Data Analysis of the LOOP Marine and Estuarine Monitoring Program, 1978–95

Volume 3: Physical Hydrography

LSU-CEI-97-03:3

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DATA ANALYSIS OF THE LOOP MARINE AND ESTUARINE MONITORING PROGRAM, 1978–95

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VOLUME 3: PHYSICAL HYDROGRAPHY
FINAL REPORT

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LTRC Project No. 97-331 MP
State Project No. 736-99-0449
LSU Project No. 169-25-4115

Conducted for
Louisiana Transportation Research Center

This is Volume 2 of a six volume set that includes: Volume 1: Executive Summary; Volume 2: Water Chemistry; Volume 3: Physical Hydrography; Volume 4: Zooplankton and Ichthyoplankton; Volume 5: Demersal Nekton; and Volume 6: Sediment Quality.

December 1997

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ACKNOWLEDGMENTS

This work was supported by a grant from the Louisiana Transportation Research Center, Louisiana State University. This particular report is only a part of the larger project analyzing the environmental impacts on water chemistry, zooplankton and ichthyoplankton, demersal nekton, and sediment quality. The data was collected and prepared for distribution to the authors by the staff of the Louisiana Department of Wildlife and Fisheries. Dr. J. Geaghan of the Louisiana State University Department of Experimental Statistics constructively assisted in the analysis.

I. EXECUTIVE SUMMARY

A. INTRODUCTION

The complex region of interest is associated with the Mississippi River deltaic plain. The estuarine portion (Barataria Basin) has resulted from the subsidence of abandoned river distributaries and associated marsh; the offshore region is strongly influenced by the discharge plumes from the present delta. The hydrographic data sets collected by LOOP are the longest continuous records from this region and clearly define the interannual and intra-annual hydrographic variability of the area. The most complete of these concern the temperature and salinity variations.

B. METHODS

These data sets are used to estimate statistics which objectively characterize the hydrography of the region, to estimate the presence of trends and/or changes in this character during the course of LOOP operations, and to determine the possible causes of any such changes identified.

The data were collected by LDWF using standard technologies. Some data sets were from continuous recorders while others were from stations sampled at nearly regular intervals. The records were quality controlled and the final data sets analyzed using standard statistical techniques, both parametric and non-parametric. Particular emphasis was placed on estimating changes before and after important LOOP-related activities (major brine discharges following construction, cessation of brine discharge, oil spills) and significant environmental events (Hurricane Andrew, the active 1985 hurricane season, the freeze of 1989, variations in Mississippi River flow).

The region was divided into four sub-regions having different hydrographic characteristics and different dominant physics: an offshore region dominated (at least in the surface layers) by the effluent plumes of the Mississippi River, a nearshore region where the influence of the coast directed flow parallel to shore and shallow waters permitted strong air-sea interactions, a lower estuarine region where broad areas of open water connected to the nearshore region through multiple tidal inlets allowing significant exchange of estuarine and coastal water, and an upper estuarine region of broad shallow lakes interconnected by narrow bayous and tidal channels which restrict exchange processes. Each region was considered separately.

C. RESULTS

The seasonal variability in each region was consistent with patterns observed in earlier, less comprehensive studies. Temperatures varied in response to summer heating and winter cooling. Salinities responded to the discharge pattern of the Mississippi River and to local rainfall and evaporation. Interannual variability was less than intra-annual variability in both parameters.

Trends in parameters were observed at many, but not all, stations. These trends were most common in temperature and were generally positive. Two near-bottom stations in the offshore region showed positive salinity trends and two stations in the lower estuary showed negative salinity trends. Other trends were not spatially coherent and often resulted from short records which could have been strongly influenced by climatological variability. The most spatially-coherent signals were increasing temperature trends at offshore stations. These may have been due to the effects of Loop Current rings. An adequate time series of Loop Current variability was not available to test this hypothesis. We could not develop a rational hypothesis for how Loop activities could alter these hydrographic variables other than an alteration of estuarine flow patterns. There was no indication of such an effect.

BACI analyses did not indicate any statistically significant interaction term except for the analysis of oil spill impacts on bottom salinity at the offshore terminal. The before:after contrast, though, was insignificant suggesting that the control and impact stations were different, but not due to the spills.

D. CONCLUSION

We were unable to identify a clear change or trend in hydrographic variables attributable to Loop activities. The hydrographic data set, though, defines the interannual and intra-annual variability of these parameters for comparison with biological and water chemistry parameters. This will allow identification of changes in covariates, if the biological changes are observed. Continuation of this data set is probably advisable as proposed alterations to the Mississippi River discharge pattern may be expected to result in habitat alterations in the future.

II. INTRODUCTION

A. LOUISIANA OFFSHORE OIL PORT

The Louisiana Offshore Oil Port (LOOP) facilities in coastal Louisiana provide the United States with the country's only superport for off-loading deep draft tankers. The facilities are located in Lafourche Parish in southeast Louisiana, south of New Orleans and adjacent offshore waters west of the Mississippi River Delta. The development is operated by LOOP LLC., a private corporation owned by Shell Oil Company, Texaco Inc., Ashland Inc., Murphy Oil Corporation, and Marathon Pipeline Company.

LOOP INC., (later restructured as LOOP LLC) was organized in 1972 as a consortium of companies to design, construct and operate a deepwater port on the Louisiana coast. Pre-permit baseline studies related to the proposed development were conducted from 1972 to 1975. Major documents related to these studies are listed in Table 1. State and federal licenses to own and operate a deepwater port were issued in January 1977, and accepted on August 1 1977. The state license was issued to LOOP pursuant to the Louisiana Offshore Terminal Act (LA R.S. 34:3101 et seq.). A federal *License to Own, Construct and Operate a Deepwater Port* was issued to LOOP by the U.S. Department of Transportation (USDOT) pursuant to the federal Deepwater Ports Act (33 U.S.C. 1501, et seq.). The first oil tanker was offloaded on May 5, 1981.

B. FACILITY DESCRIPTION

The superport complex consists of an offshore marine terminal located about 30 km from the mainland in the Gulf of Mexico, an onshore storage facility at the Clovelly salt dome near Galliano about 50 km inland from the coast, and a large diameter pipeline system including a pumping booster station near Fourchon onshore to deliver oil to the storage facility. The pipeline system

TABLE 1

LIST OF REPORTS PRODUCED FOR SUPERPORT PLANNING

(AFTER SASSER ET AL. 1982)

Year	Title	Comment
1972	LOOP feasibility study	LOOP's Engineering Feasibility Study
1972	A Superport for Louisiana	Superport Task Force Report
1972	LSU Superport Study #1	Requested by Superport Task Force
1972	LSU Superport Study #2	Requested by National Sea Grant Program
1973	LSU Superport Study #3	Requested by LOTA to formulate EPP
1973	LSU Superport Study #4	Requested by LOTA to formulate EPP
1974	Alternate Site Location Evaluation	Prepared by Dames and Moore for LOOP, Inc.
1976	Environmental Baseline Studies Vols. 1–4	Prepared by LSU for LOOP, Inc.
1976	Environmental Impact Study	US Department of Transportation

also connects the Clovelly salt dome oil storage facility to transportation facilities on the Mississippi River. A large brine storage reservoir (101 ha) is positioned near the Clovelly salt dome storage facilities. A small-boat harbor and logistics facility is located at Port Fourchon, on Bayou Lafourche.

The marine terminal consists of three Single Point Mooring (SPM) structures connected by pipelines to a platform-mounted pumping station in the Gulf of Mexico, 30 km southeast of Belle Pass, Louisiana. Water depth at the platform is 36 m. From the offshore marine terminal facility, crude oil is pumped northward through a large diameter (56 inch) buried pipeline, through the onshore booster station at Fourchon, to the Clovelly salt dome storage complex near Galliano. The crude oil is stored in caverns constructed in subterranean salt domes. These storage chambers were formed by solution mining utilizing local surface water in the area. A second pipeline extends southward parallel to the oil pipeline and carries brine leached from the Clovelly storage facility to the diffuser disposal site located in open Gulf of Mexico waters approximately 4.8 km (3 mi.) offshore and adjacent to the LOOP oil pipeline. Additional distributary pipelines move oil from the Clovelly complex to outlying pipelines and refining centers.

C. PROJECT AREA

The Barataria estuary and the offshore area in which LOOP is located is an extremely diverse and complex natural system. It is located in the Mississippi River Deltaic Plain region. This region was formed and is continually influenced by processes associated with the deposition of massive amounts of sediments carried by the Mississippi River. The LOOP pipeline traverses the major wetland habitats in the Louisiana coastal area. The 159 km pipeline crosses the near-offshore Gulf of Mexico, beach/barrier headland, and estuary. Within the estuary, four salinity zones - saline, brackish, intermediate and fresh - are traversed, each providing a unique habitat supporting a variety of species.

The coastal marshes of Louisiana are one of the most productive ecosystems in the world, supporting a wide variety of estuarine-dependent organisms. Louisiana leads fishery production within the northern Gulf of Mexico and is second only to Alaska among all states (NMFS 1997). Louisiana is the leader in the United States for the production of shrimp, blue crab, oyster, crawfish, tuna, red snapper, wild catfish, black drum, sea trout, and mullet (McKenzie et al. 1995). Ninety-five percent of the Louisiana fish and shellfish landings are estuarine-dependent species (McKenzie et al. 1995). The fish community of Barataria estuary is the most diverse of any estuary in Louisiana with 191 species from 68 families (Condrey et al. 1995).

D. MONITORING PROGRAM

In recognition of the potential for significant environmental impacts much attention was given to environmental safeguards by state and federal agencies and by the superport developers (see review by Sasser et al. 1982). Because of the potential risks associated with the construction and operation of the superport (e.g. bringing the world's largest oil tankers to one of the most productive fisheries resources in the world), both state and federal licenses required environmental monitoring of LOOP construction and operational activities. The environmental monitoring program (EMP) was developed under mandate of the Superport Environmental Protection Plan (revised, 1977), a regulation of the State of Louisiana implementing the Offshore Terminal Act. Components of the estuarine/marine monitoring program include: water chemistry, physical hydrography, brine discharge, zooplankton/ichthyoplankton, demersal nekton, benthos, and sediment quality. The Louisiana Department of Wildlife and Fisheries collected the data related to these components from 1978 to 1995. Vegetation and wildlife components were monitored by LSU (see Visser et al. 1996 and references therein). This report is the second component in a series of five reports that analyze of the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment. These five reports analyzed the following components: 1) Water Chemistry, 2) Physical Hydrography, 3) Zooplankton / Ichthyoplankton,

4) Demersal Nekton, and 5) Sediment Quality.

E. LITERATURE REVIEW

The region of interest is complex and the hydrographic character of each associated sub-region responds to the dominance of different dynamics and external forcing factors. Within the study area, we can identify both a mid-shelf and inner shelf sub-region of the coastal bight immediately west of the Mississippi delta. This region has been referred to as the Louisiana Bight (Wiseman et al. 1982, Rouse and Coleman 1976). The estuarine (in the sense of Pritchard 1967) portion of the study area can also be subdivided into an open water, lower estuary and complex, inter-connected upper estuarine region.

The dominant feature of the bight west of the Mississippi delta is the effluent plume from Southwest Pass (Rouse and Coleman 1976, Wiseman et al. 1974, Wiseman et al. 1975, Walker 1996, Rouse 1997), which often makes an anticyclonic (clockwise) turn within the bight before merging with a coastal current near shore. The dynamics of the region are poorly understood. Wind forcing appears to be important (Rouse and Coleman 1976, Rouse 1976). Mixing is complicated (Wiseman et al. 1975), and the impact of biological processes on the distribution of water properties remains an open question (Hitchcock et al. 1997). Tides are diurnal and small (Marmer 1954). Inertial oscillations are important (Daddio et al. 1978). Most hydrographic studies of the area have been of short duration, a few years at most. Seasonal water mass variability has been defined (Wiseman et al. 1982) from the data collected during the LOOP environmental assessment (Wiseman et al. 1974). The other long-term data set (Temple et al. 1977) was used extensively in the broader scale studies of Cochrane and Kelly (1986) and Dinnel and Wiseman (1986). Data collected by NOAA's Nutrient Enhanced Coastal Ocean Program (NECOP) cruises have been presented separately in a number of locations (e.g. Rabalais et al. 1991). These data were largely collected during mid-summer monitoring cruises, but indicate significant inter-annual variability. Other data sets are of less than a year in duration, e.g. Turner and Allen (1982).

As the effluent plumes from the Mississippi River approach within one Rossby radius (Gill 1982) of the coast, the presence of a coastal boundary directly influences the flow dynamics (Gill 1982, Csanady 1981). The flow turns westward along the coast (Cochrane and Kelly 1986, Wiseman and Kelly 1994) although reversals due to wind forcing can occur on a regular basis (Dinnel et al. 1997, see also discussion of flow variability below). The hydrographic characteristics of this region were included in the analysis of Wiseman et al.(1982) and are similar to those observed at a nearshore station further westward offshore of Cocodrie (Wiseman et al. 1997).

Within the estuarine portion of the study area, a number of studies including water mass properties have been carried out. Those involving the longest records are Wiseman et al. (1990a, 1990b). The most important conclusion from these studies was that the low-frequency salinity variability could be adequately represented using an auto-regressive, moving average model forced by Mississippi River discharge. This implied that higher frequency processes effectively flushed estuarine waters from the system and exchanged them with coastal ocean waters. The processes involved, by analogy with Terrebonne Bay (Wiseman and Inoue 1993, McKee et al. 1994) and inspection of the power spectra of the salinity records from the Barataria Basin, are tidal exchange and wind-driven exchange (Kjerfve 1973, Kjerfve 1975, Byrne et al. 1976, Schroeder and Wiseman 1986). Flushing times for different portions of the estuary have been estimated by Von Arx (1949) and Wiseman and Swenson (1989), among others. Numerical models of the system have been developed by Hacker (1973), D.-H. Park (personal communication) and Suhayda and Aravamuthan (personal communication). The first description of the seasonal variability of salinity conditions within the system of which we are aware is Barrett et al. (1971). This description has not altered significantly, although description of the interannual modulation has been refined.

In the upstream end of the estuary, a series of small lakes are interconnected by a convoluted patchwork of bayous and canals. Some are artificially deepened to allow ship traffic. Tidal propagation within these is poorly understood and wind-driven flows are equally poorly defined by existing models. This is partially due to the scales of resolution of the models and to the lack of good bathymetric data for the models. It is clear that freshwater runoff is important to the seasonal circulation. Evapo-transpiration (Wax et al. 1978) will play a modifying role. The lack of adequate rainfall data to define the variability of this important driving function is restricting our understanding of circulation and exchange patterns. These will, probably, be significantly altered in the near future, if major planned diversions of the Mississippi River into Barataria Basin occur.

It is unclear to what extent the time varying (and possibly reversing) baroclinic pressure gradients developed between the fresher estuarine waters and the coastal waters drive a significant, low-frequency flow component as they do, for example, in the Magothy River (Pritchard and Bunce, 1959). It is obvious, though, that modulation of the salinities of the coastal ocean by variations in Mississippi River discharge alters the salinity patterns of the estuary.

F. ANALYTICAL OBJECTIVES FOR THE HYDROGRAPHIC DATASETS

Following the completion of quality assurance and quality control on these data, the analytical objectives for the hydrographic datasets to be addressed include both a general description of the data and impact analyses. The EMP (section 3.1, page 8, March 1986) lists the objectives of the monitoring program as:

(1) to obtain seasonal environmental and ecological data so that conditions existing during operation can be related to historical baseline conditions;

(2) to detect during the operation of the project any adverse alterations or damages to the environment so that corrective action can be taken as soon as possible;

(3) to obtain sufficient data to determine the cause or causes of environmental damages or alterations so that responsibility can be properly placed; and

(4) to provide information in order to evaluate long and short-term impacts of the project.

The general goal of our data analysis program was to analyze and report on the LOOP Marine/Estuarine environmental monitoring data collected from 1978-1995, with respect to the EMP objectives.

- We define the seasonal variability of the hydrographic properties of the study region. In particular, means and variances are estimated along with long term trends in these properties. Other important statistics of the data sets are identified.

- We test for any anomalous changes in these properties during operation and/or construction of the LOOP facilities.

- Where such changes are identified, we attempt to identify possible causes of these changes.

- We attempt to interpret the available data so that future changes in the hydrography of the environment or concurrent changes in the biota may be identified as anomalous or due to expected environmental stochastic variability.

III. METHODS

A. FIELD

The LDWF deployed 13 stations to constantly record high resolution time series of temperature and salinity, located in both estuarine and offshore regions as depicted in Figure 1. Current direction and speed were also recorded at stations 306, 318, 319, and 335. The type of instrumentation used at these fixed stations and period of use for each type of instrument is detailed specifically for each station in Figure 2. The high resolution measurement frequencies varied from once per minute to once per hour, depending on the station, and sometimes changing at individual stations. These measurements of variable frequency were converted to hourly values by Coastal Studies Institute personnel as described below.

The time series data collected at these fixed station locations were supplemented by monthly measurements of temperature and salinity that were taken at top, middle, and bottom depths at 152 stations throughout the study region over a period of 18 years. Salinity was measured at inshore stations using a Beckman RS5-3 portable salinometer during the years 1978-1989. During the years 1990-1995 a Hydrolab Surveyor 2 was used, although sometimes the Beckman instrument was used for inshore salinities as a backup. From 1978-1984, the Martek Mark VI was used at offshore stations with numbers in the 700's (Figure 3). During these years, the Beckman RS5 was used at stations 21, 22, 35, 36, 37, 52, 53, 54, and 55, though the Martek instrument was used as an occasional backup. From 1985-1995, a Guildline CTD was used at offshore stations; a CTD is a standard oceanographic instrument for measuring conductivity, temperature, and depth. From 1990-1995, the Seabird SBE19 CTD was used offshore as a backup instrument. Monthly measurements at these stations provided a broad spatial sampling of temperature and salinity fields in the study area over the full eighteen years of the study, although of a lower sampling frequency than at the fixed stations.

Salinity was also recorded on a monthly basis at top, middle, and bottom levels at 42 water chemistry stations. This was done from 1978-1984 by titration; after that time an Autosal

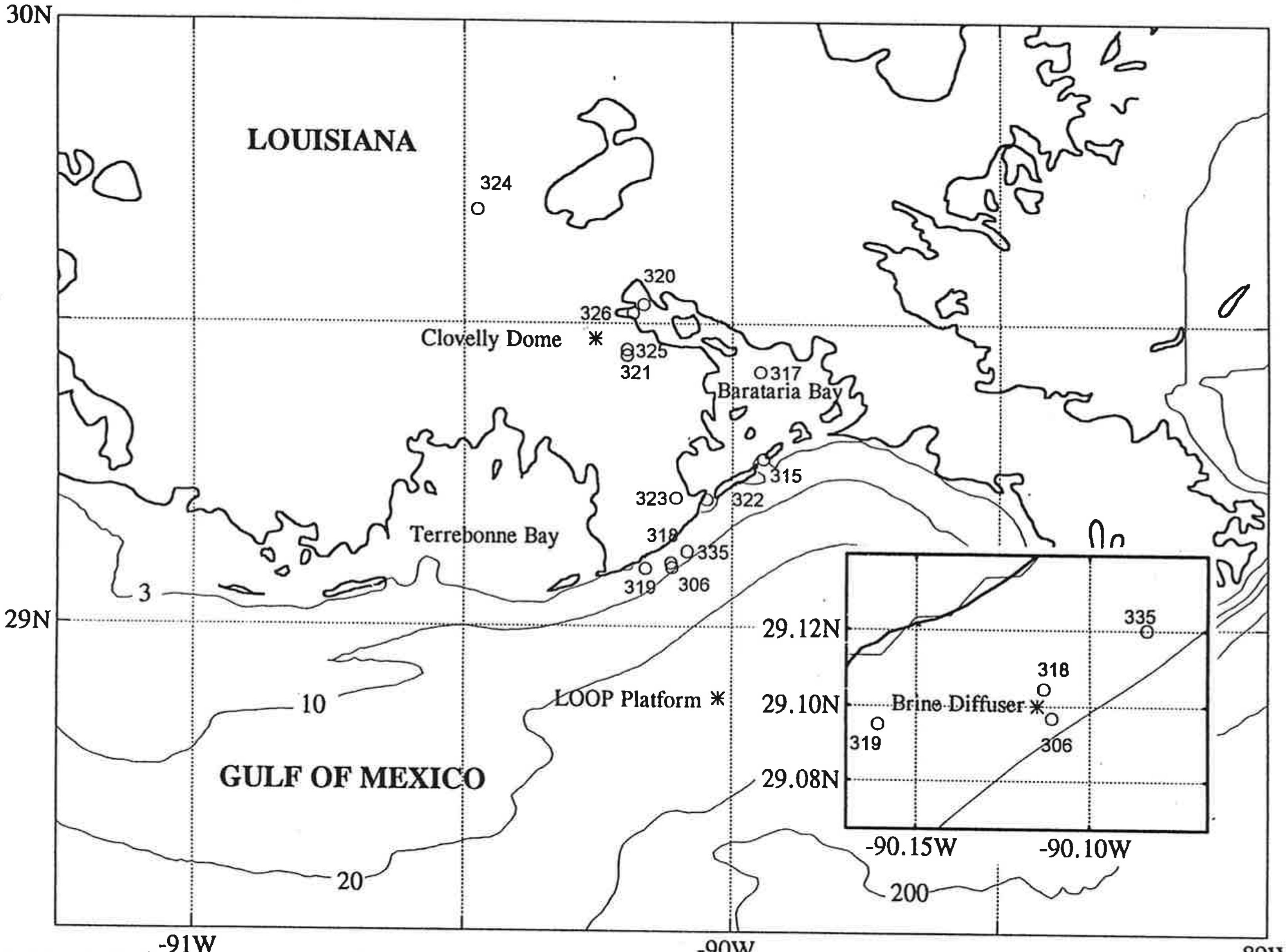

Figure 1. Fixed station locations at which temperature and salinity were measured; in addition to these variables, current speed and direction were measured at stations 306, 318, 319, and 335. Inset (5:1) shows location of brine diffuser.

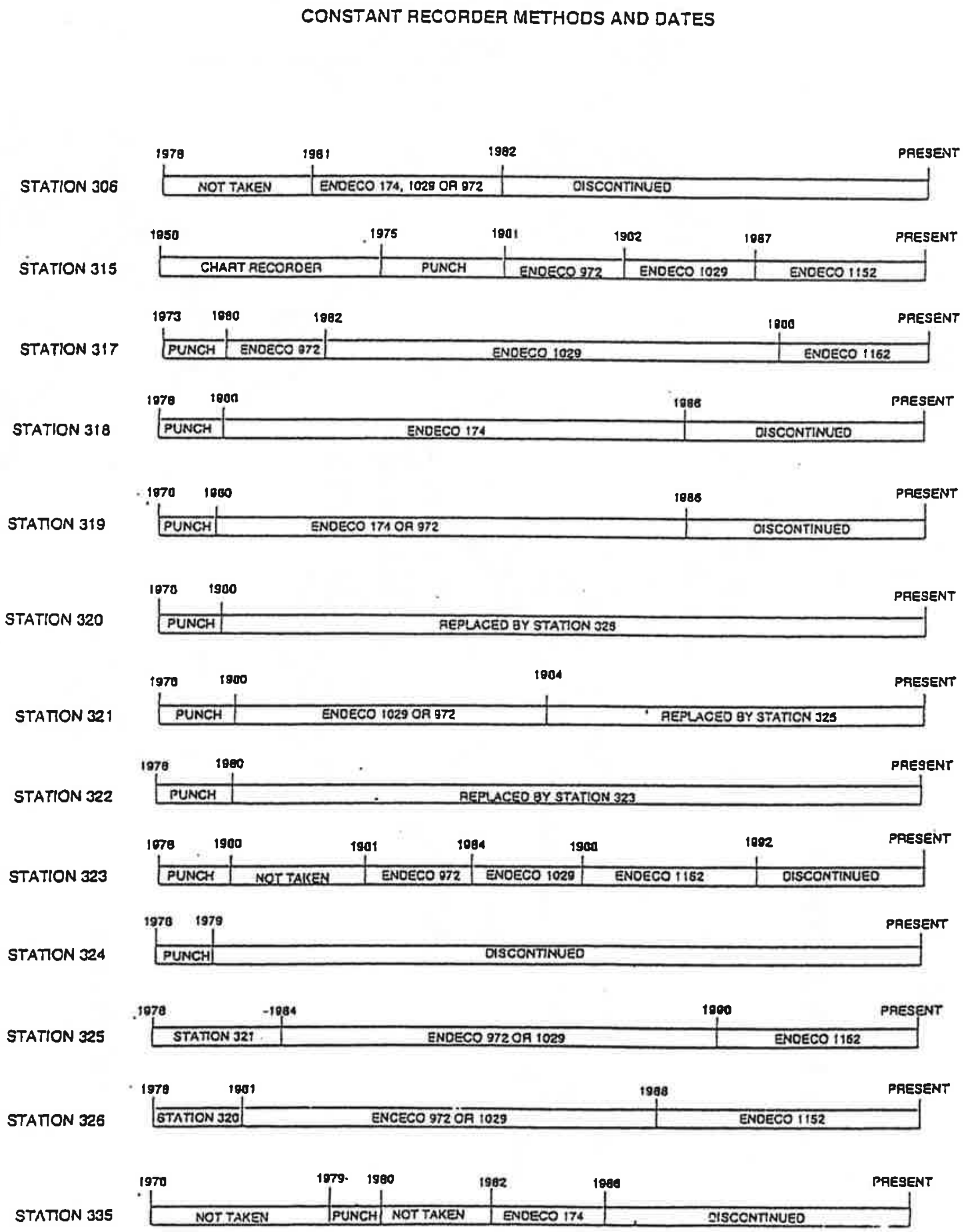

Figure 2. Constant recorder methods and dates. Figure courtesy of LDWF.

analyzer was employed. These water chemistry salinity data were collected concurrently with some of the physical hydrography data, and were used in this study to verify the monthly physical hydrography salinity data. Although the water chemistry data were measured using preferred methods and instruments, there are more stations and more measurements available in the dataset designated for the study of physical hydrography.

LDWF also recorded 1143 profiles of temperature, salinity, oxygen, and pH collected by CTD from 1988-1995 at 25 stations throughout the study region. The temperature and salinity profiles were used to supplement time series data in this study.

Water level measurements and cumulative precipitation measurements were made from 1978-1980 at stations 315, 320, and 322 (water level only). The importance of freshwater derived from land drainage to an understanding of the hydrography and flow patterns within the estuarine waters of the Barataria system was mentioned in the introduction. A good record of long-term precipitation from this basin is not available. A few short period records were collected during the monitoring program, but these are not of a length which lend themselves to an analysis of seasonal variability or interannual trend analysis. The absence of such records will continue to inhibit a comprehensive description of the physical hydrography of the basin.

B. LABORATORY/COMPUTER PROCESSING OF DATA

A modified data set was created for use in the analysis of the physical hydrography data. This was done using common procedures that prepare instrument output for use by the scientific community. This section of the report contains both a description of the procedures used by Coastal Studies Institute personnel to create the modified dataset, as well as the method of verification of the physical hydrography salinity data using salinity data from the water chemistry dataset.

Discrete monthly measurements of salinity, temperature, depth of measurement, seafloor depth, and additional physical hydrographic variables were taken by LDWF at top, middle, and bottom depths at 152 stations of known location. Outliers more than five standard deviations from the local mean were removed from monthly temperature and salinity samples. This method of outlier removal is a standard quality control procedure used in physical oceanographic projects such as LATEX, the Louisiana-Texas Shelf Physical Oceanography Program (Jochens and Nowlin, 1994). Because stratification in the region is known to be stable and dominated by salinity structure, bottom salinity values recorded simultaneously with mid-depth salinity values that exceeded them were discarded. Further monthly or quarterly measurements of salinity from the water quality (chemistry) data at 42 stations were processed also. Headers were added to the physical hydrography and water quality data files which include general information, data format, Fortran format of the data, specification of flags used to indicate any missing values, and identification of the information and units of measurement in each column. A very important part of creating a dataset suitable for scientific use is the creation of regular columns of information. These include columns for station number, decimal day following 1/1/78 0000 at which the sample was collected, seafloor depth, sampling depth, and salinity for the water quality data file, as well as temperature, east current velocity, and north current velocity columns for the physical hydrography data file.

Hydrographic profiles of temperature, salinity, and oxygen were visually inspected; obvious outliers were identified and removed manually and gaps were flagged and recorded.

The high resolution time series data from stations 306, 315, 317, 318, 319, 320, 321, 323, 324, 325, 326, and 335 were reduced to hourly values from varied and inconsistent higher resolution sampling frequencies by means of linear interpolation of the nearest values within 30 minutes before and after the hour. Another procedure that could have been used is to estimate variable values on the hour by an hourly mean, a useful technique that inherently smooths the data but requires a weighting algorithm in data that are collected at variable sampling frequencies. Gaps in the hourly rendition of the data that spanned from 2-20 hours were filled by means of linear interpolation. Larger gaps were left intact. Temperature, salinity, east velocity, and north velocity values that exceeded three standard deviations from the local mean were removed. Standard headers were added to each high resolution data file and these include general information, station number, geographic coordinates, start and stop dates for recorded measurements, data format, Fortran format of the data, specification of flags used to indicate any missing values, and identification of the information and units of measurement in each column.

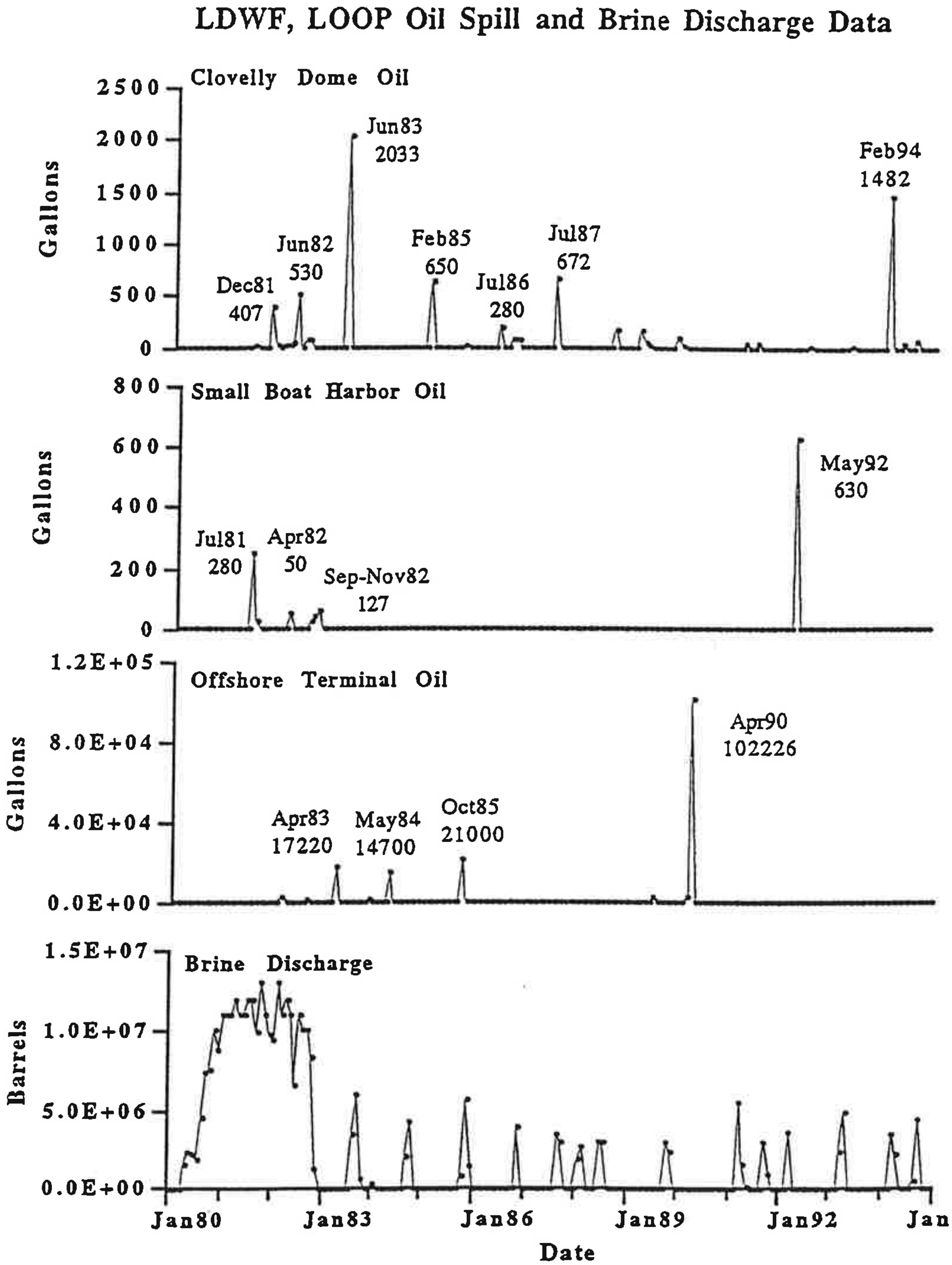

Figure 4. Time series plots of oil spills and brine discharge. Plots represent (top to bottom) gallons of oil spilled at the Clovelly Dome oil storage area, the Fourchon small boat harbor, the offshore terminal, and the barrels of brine discharged at the offshore diffuser. The dates and amount of oil spilled, for the more noticable peaks on the plot, are listed.

TABLE 2

SUMMARY OF STATISTICAL TECHNIQUES USED TO INVESTIGATE POSSIBLE IMPACTS OF LOOP

Listed, for each potential impact type, is the time period over which the impact did (and did not) occur, the LDWF stations used in the analysis, and the type of analysis. The stations are classified as a control, a low impact or a high impact station.

	Time Period			Stations Used			
Impact	Before	During	After	Control	Low Impact	High Impact	Statistical Tests
Construction	<Jan79	>Jan79	>Dec80	5		34	BACI Model
		<=Dec80		12		7	
				15		38	
				14			
Brine Pumping	<May80	>May80	>Dec82	21		22	BACI Model
		<=Dec82		35		36	
				502			
Oil Spills							
Clovelly Dome	<Dec81	>=Dec81	>Feb94	15		38	BACI Model
		<=Feb94		14			with oil spilled
							as covariate
Offshore Terminal 1	<Apr83	>Apr83	>Apr90	704		53	BACI Model
		<=Apr90		706		55	with Oil spilled
				707		708	as covariate
						52	
						54	
Offshore Terminal 2	<Apr83	>Apr83	>Apr90	704	52	53	BACI Model
		<=Apr90		706	54	55	with Oil spilled
				707		708	as covariate

IV. RESULTS AND DISCUSSION

A. GENERAL DISCUSSION OF PHYSICAL RESULTS

General descriptive statistics including mean, minimum, maximum, and standard deviation for salinity, temperature, east current velocity, and north current velocity time series, were calculated from available time series records. These statistics were computed for temperature and salinity time series spanning all or part of the years 1978-1995, for those stations at which 20 or more monthly measurements were recorded over the nearly 18 year study period. Statistics were obtained separately for top , middle, and bottom monthly samples at 93 stations at which physical parameters were measured, and at 44 stations at which chemical parameters were measured (Appendix A). Mean measured seafloor depth and sampling depths, and number of measurements used to compile statistics are also tabulated. Appendix A also contains general descriptive statistics for salinity, temperature, east current velocity, and north current velocity data (as available) collected at an hourly or higher sampling rate at 12 stations. Current velocities were available at stations 306, 318, 319, and 335. Figure 3 illustrates the locations of those stations at which the most monthly sampled data were obtained, and Figure 1 depicts the locations of all stations at which the high resolution time series were collected.

The statistics presented in Appendix A illustrate very clearly the influence of freshwater outflow on the upper areas of the marsh as decreasing salinity means at stations 14, 15, 16, 18, and 38, for example. Stations at locations such as St. Mary's Point (Station 317) exhibit relatively high standard deviations for salinity that may be due to occasional influxes of Gulf of Mexico water into Barataria Bay, temporarily elevating salinity, freshets following major rainfall events, temporarily lowering salinity, and the advection of strong salinity gradients past the sampling site by tidal and subtidal currents. Surface temperatures are more evenly distributed, probably due to the effectiveness and uniformity of heat exchange at the surface boundary. Bottom temperature means are consistently lower than surface temperature means, reflecting the influx of heat energy at the sea surface.

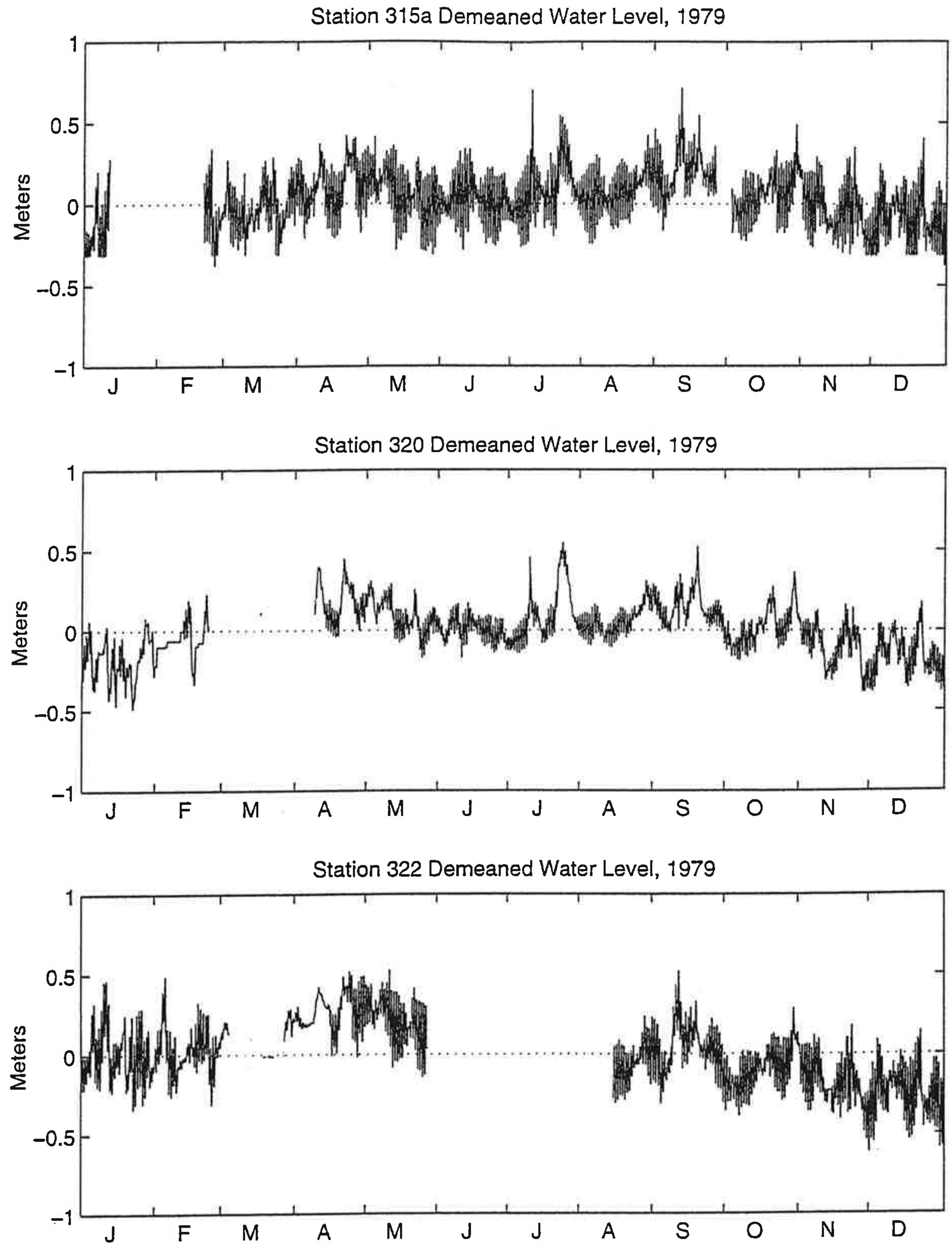

Figure 6. Demeaned water level time series at stations 315, 320, and 322 during 1979.

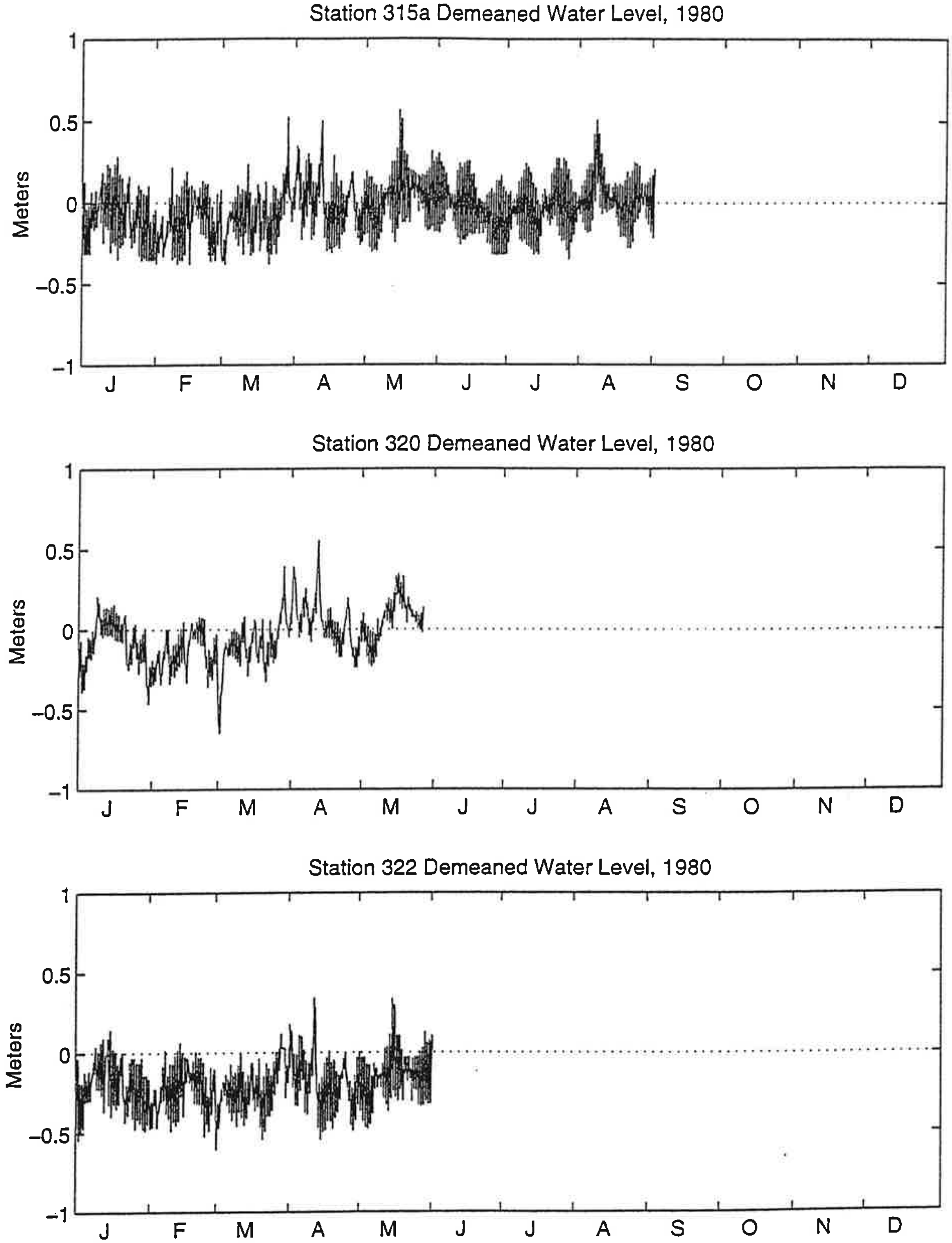

Figure 7. Demeaned water level time series at stations 315, 320, and 322 during 1980.

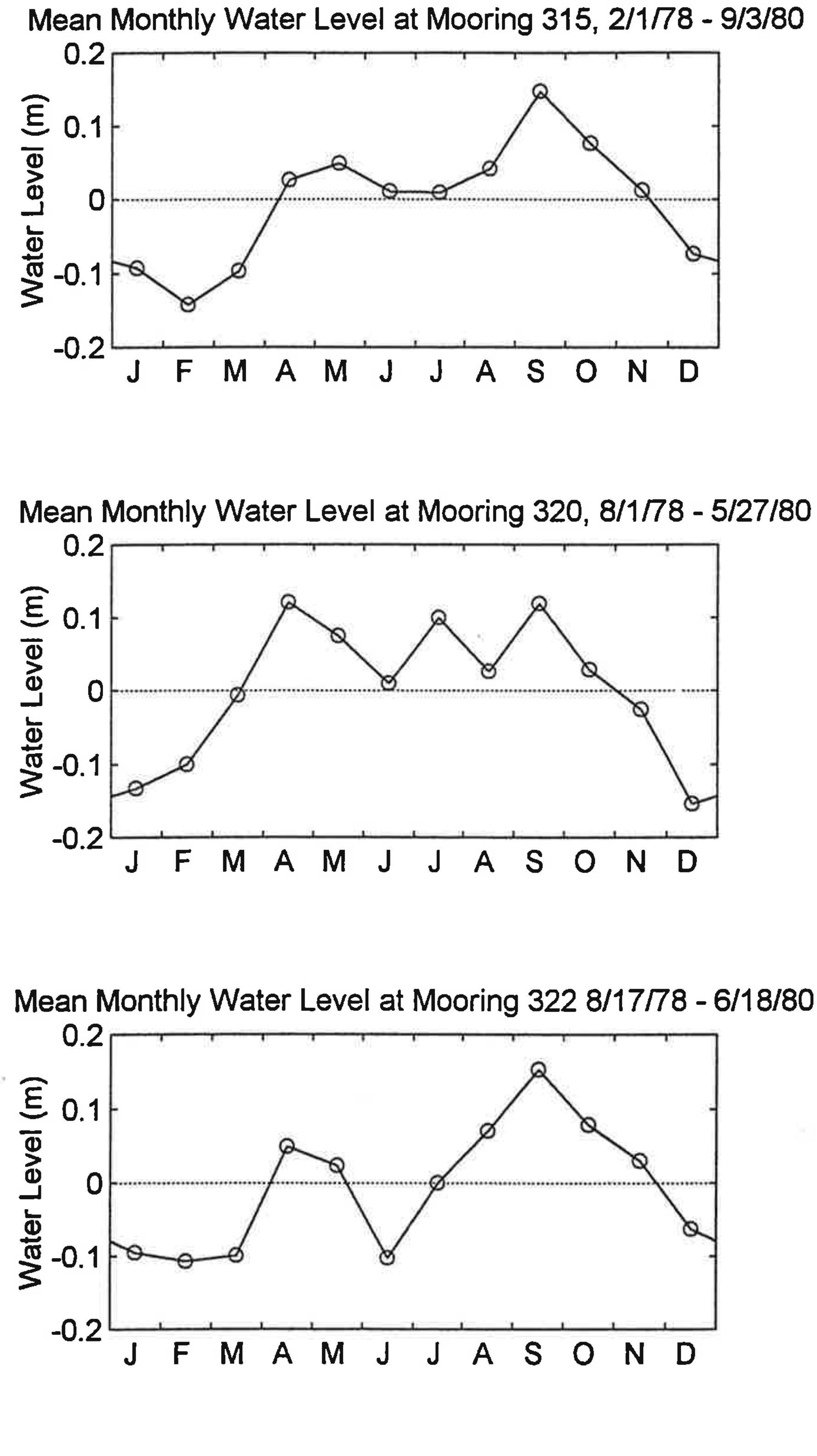

Figure 8. Mean annual water level cycle; means for each of the 12 months of the year computed from the individual 1978-1980 records taken at stations 315, 320, and 322.

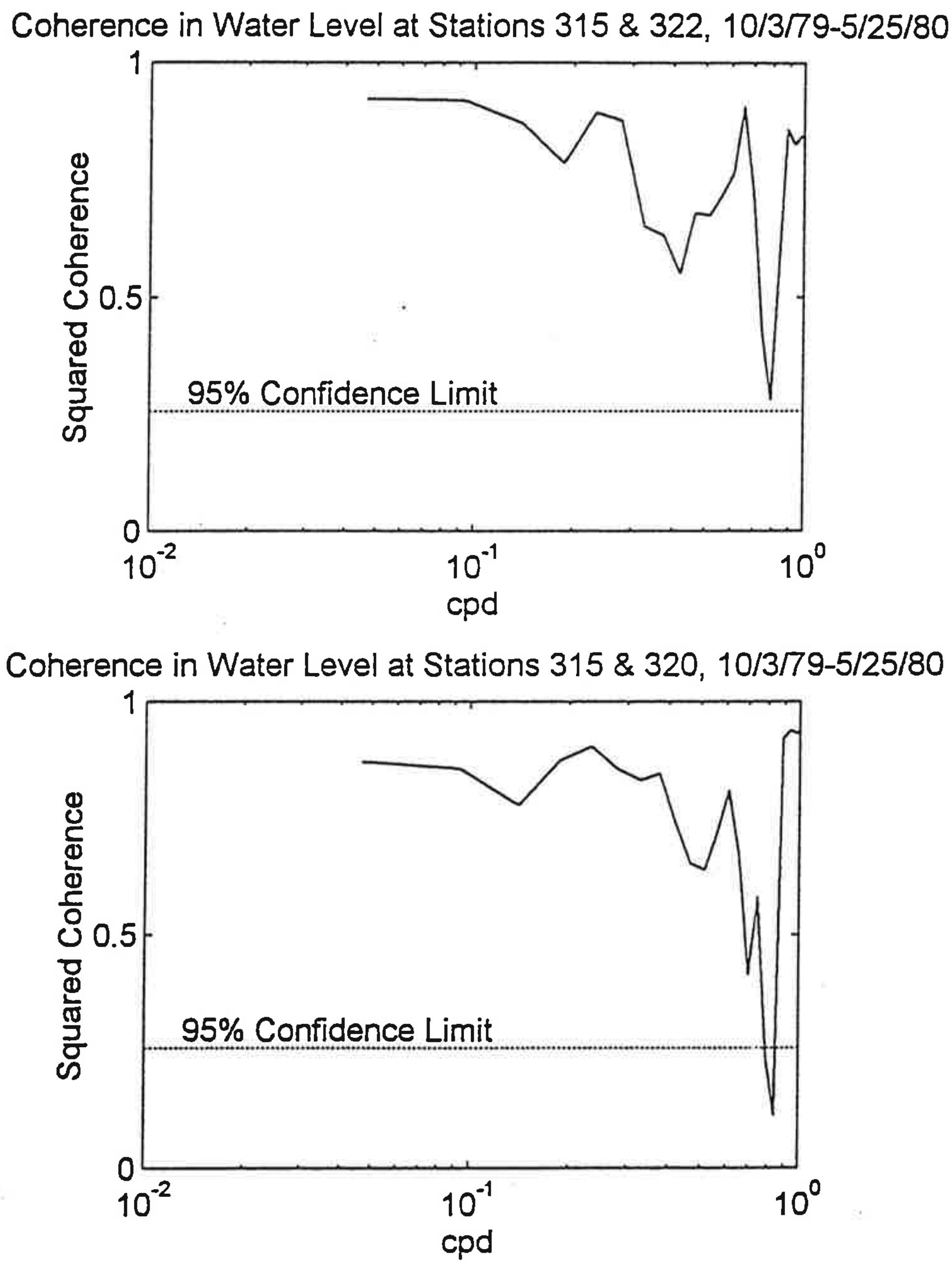

Figure 9. Coherence between water level records taken at stations 315, 320, and 322. Frequency is in units of cycles per day.

Results of long term trend analyses for salinity and for temperature for surface and bottom monthly measurement time series are summarized in Tables 3-6. The trend tables in Appendix E specify probability of a trend existing at each selected station for the entire period of nearly eighteen years and for periods before and after seven events to be studied for effects on long term trend, and Tables E61 and E62 list the probability of trend existing at fixed stations over the span of their records. This was accomplished using the standard Kendall tau and the seasonal Kendall tau tests for trend. The masking effects of seasonality on determination of trend explains the $p_{nonseasonal}$ values, which in this study are less frequently significant than are the probabilities of trend determined using the seasonal Kendall tau method ($p_{seasonal}$) for the times series examined in this study. Slope of the trend using linear regression (B_1) differed from that estimated using the seasonal Kendall tau method (B), as might be expected in comparing the results of a parametric method with those of a nonparametric method; still, sign of the slope generally appears to be the same.

The three hurricanes of 1985, including Hurricane Juan, were not related to significant long term trends in upper layer salinity or temperature, or in bottom salinity. The change in bottom temperature trends at five of the seven offshore stations is apparent in upper layer temperature trends at two offshore stations, and was not detected at the other five offshore stations. One may conclude that it is unlikely that any change in long term temperature or salinity trends, in the upper or bottom layers, was caused by these three hurricanes.

Hurricane Andrew also did not appear to affect the prevelance of significant long term trends in upper layer temperature, though the stations at which these increasing long term trends were detected after Hurricane Andrew tended to be further offshore. Curiously, an increase in the number of stations at which significant offshore long term bottom temperature trends occurred following Hurricane Andrew in 1992 is similar to the increase in offshore long term bottom temperature trends following the 1985 hurricane season. Since significant surface warming trends did not become more frequent after this hurricane, one may only conclude that the bottom warming may be a response to some other occurrence. Following Hurricane Andrew, eleven stations were found to have recorded significant increasing trends in near surface salinity, and it is possible that this could be a response to the severe effects of this particular hurricane across the study area.

TABLE 3

SUMMARY OF BOTTOM SALINITY TRENDS

Numbers of stations at which positive and negative trends were detected with probability greater than 0.95, and total number of stations analyzed for trend, for each time period.

Description of Time Period	+	-	total
Entire Study Period	2	0	17
Before 1985 Hurricane Season (1/1/78-12/31/84)	0	0	17
After 1985 Hurricane Season (1/1/86-12/31/95)	0	0	16
Before Year of No Brine Discharge (1/1/78-12/31/89)	8	0	17
After Year of No Brine Discharge (1/1/90-12/31/95	1	0	16
Before Hurricane Andrew (1/1/78-8/10/92)	2	0	17
After Hurricane Andrew (8/30/92-12/31/95)	2	0	16
Before Start of Heavy Brine Disposal (1/1/78-3/31/80)	0	0	5
After Heavy Brine Disposal Ceased (1/1/83-12/31/95)	3	0	17
Period of Light River Outflow (1/1/78-12/31/82)	3	0	17
After Start of Heavy River Outflow (7/1/83-12/31/95)	2	0	17
Before the Big Freeze of 1989 (1/1/78-12/1/89)	8	0	17
After the Big Freeze of 1989 (1/1/90-12/31/95)	0	0	16
Before the April, 1990 Oil Spill (1/1/78-3/31/90)	7	0	17
After the April, 1990 Oil Spill (5/1/90-12/31/95)	0	0	16

TABLE 4

SUMMARY OF BOTTOM TEMPERATURE TRENDS

Numbers of stations at which positive and negative trends were detected with probability greater than 0.95, and total number of stations analyzed for trend, for each time period.

Description of Time Period	+	-	total
Entire Study Period	6	0	17
Before 1985 Hurricane Season (1/1/78-12/31/84)	0	0	17
After 1985 Hurricane Season (1/1/86-12/31/95)	5	0	16
Before Year of No Brine Discharge (1/1/78-12/31/89)	0	0	17
After Year of No Brine Discharge (1/1/90-12/31/95	3	0	16
Before Hurricane Andrew (1/1/78-8/10/92)	0	0	17
After Hurricane Andrew (8/30/92-12/31/95)	9	0	16
Before Start of Heavy Brine Disposal (1/1/78-3/31/80)	0	0	5
After Heavy Brine Disposal Ceased (1/1/83-12/31/95)	7	0	17
Period of Light River Outflow (1/1/78-12/31/82)	0	0	17
After Start of Heavy River Outflow (7/1/83-12/31/95)	7	0	17
Before the Big Freeze of 1989 (1/1/78-12/1/89)	0	0	17
After the Big Freeze of 1989 (1/1/90-12/31/95)	4	0	16
Before the April, 1990 Oil Spill (1/1/78-3/31/90)	0	0	17
After the April, 1990 Oil Spill (5/1/90-12/31/95)	2	0	16

TABLE 5

SUMMARY OF TOP SALINITY TRENDS

Numbers of stations at which positive and negative trends were detected with probability greater than 0.95, and total number of stations analyzed for trend, for each time period.

Description of Time Period	+	-	total
Entire Study Period	0	0	24
Before 1985 Hurricane Season (1/1/78-12/31/84)	0	0	24
After 1985 Hurricane Season (1/1/86-12/31/95)	0	0	24
Before Year of No Brine Discharge (1/1/78-12/31/89)	10	0	24
After Year of No Brine Discharge (1/1/90-12/31/95	2	0	24
Before Hurricane Andrew (1/1/78-8/10/92)	2	0	24
After Hurricane Andrew (8/30/92-12/31/95)	11	0	24
Before Start of Heavy Brine Disposal (1/1/78-3/31/80)	1	0	12
After Heavy Brine Disposal Ceased (1/1/83-12/31/95)	0	0	24
Period of Light River Outflow (1/1/78-12/31/82)	7	0	24
After Start of Heavy River Outflow (7/1/83-12/31/95)	0	0	24
Before the Big Freeze of 1989 (1/1/78-12/1/89)	9	0	24
After the Big Freeze of 1989 (1/1/90-12/31/95)	1	0	24
Before the April, 1990 Oil Spill (1/1/78-3/31/90)	10	0	24
After the April, 1990 Oil Spill (5/1/90-12/31/95)	0	0	24

TABLE 6

SUMMARY OF TOP TEMPERATURE TRENDS

Numbers of stations at which positive and negative trends were detected with probability greater than 0.95, and total number of stations analyzed for trend, for each time period.

Description of Time Period	+	-	total
Entire Study Period	5	0	24
Before 1985 Hurricane Season (1/1/78-12/31/84)	0	0	24
After 1985 Hurricane Season (1/1/86-12/31/95)	2	0	24
Before Year of No Brine Discharge (1/1/78-12/31/89)	4	0	24
After Year of No Brine Discharge (1/1/90-12/31/95	5	0	24
Before Hurricane Andrew (1/1/78-8/10/92)	6	0	24
After Hurricane Andrew (8/30/92-12/31/95)	7	0	24
Before Start of Heavy Brine Disposal (1/1/78-3/31/80)	0	0	12
After Heavy Brine Disposal Ceased (1/1/83-12/31/95)	4	0	24
Period of Light River Outflow (1/1/78-12/31/82)	0	0	24
After Start of Heavy River Outflow (7/1/83-12/31/95)	4	0	24
Before the Big Freeze of 1989 (1/1/78-12/1/89)	4	0	24
After the Big Freeze of 1989 (1/1/90-12/31/95)	1	0	24
Before the April, 1990 Oil Spill (1/1/78-3/31/90)	4	0	24
After the April, 1990 Oil Spill (5/1/90-12/31/95)	1	0	24

Significant long term surface warming trends were reduced to insignificant levels at six station locations after the Big Freeze of late 1989 that heavily affected Louisiana coastal regions.

Following the major brine discharge period after LOOP construction, long term temperature and salinity values did not deviate appreciably from trends over the entire eighteen year period of data collection. Few significant long term trends were detected during the two years prior to this period of major brine discharge, and this finding may be attributed to the limited data collected before this event. None of the stations near the brine discharge region (21, 22, 35, 36, 502, 535) appeared to show any significant trend in upper layer salinity, and no significant long term trends in bottom salinity were found at these stations near the brine discharge region either before or after this major discharge period.

The cessation of brine discharge during the entire year of 1990 also did not appear to affect upper layer or bottom salinity in the brine discharge region. A trend of increasing bottom salinity appeared at station 36 following the cessation of brine discharge; however, a similar trend at station 22 before became insignificant following 1990. No long term trends in upper layer salinity were found for the six stations in the brine discharge region, either before or after the period of major brine discharges from 1980-1982.

In 1983, mean Mississippi River flow reached its highest peak for the eighteen year study period (Figure 10). The hypothesis that long term trends at offshore stations (52, 53, 54, 55, 704, 706, 708) would shift towards significantly decreasing salinity was not confirmed. In fact, bottom salinities at stations 53 and 54 shifted in the opposite direction, towards significantly increasing salinity, after 1983, and none of these 7 offshore stations exhibited any significant surface salinity trends either before or after the increase in Mississippi River flow.

Not only did 1983 present the largest observed daily discharge during the study period, it also followed a period of three years of rather low annual mean discharge. Subsequent annual mean discharge was generally high (except in 1988) and very large in the early 1990s. The added density differences due to the river discharge may have prevented vertical mixing enough to increase bottom salinity noticeably at stations 53 and 54 at certain times of the year. It is unclear whether the lack of a similar signal at nearby stations reflects the fallacy of this hypothesis or sampling variability.

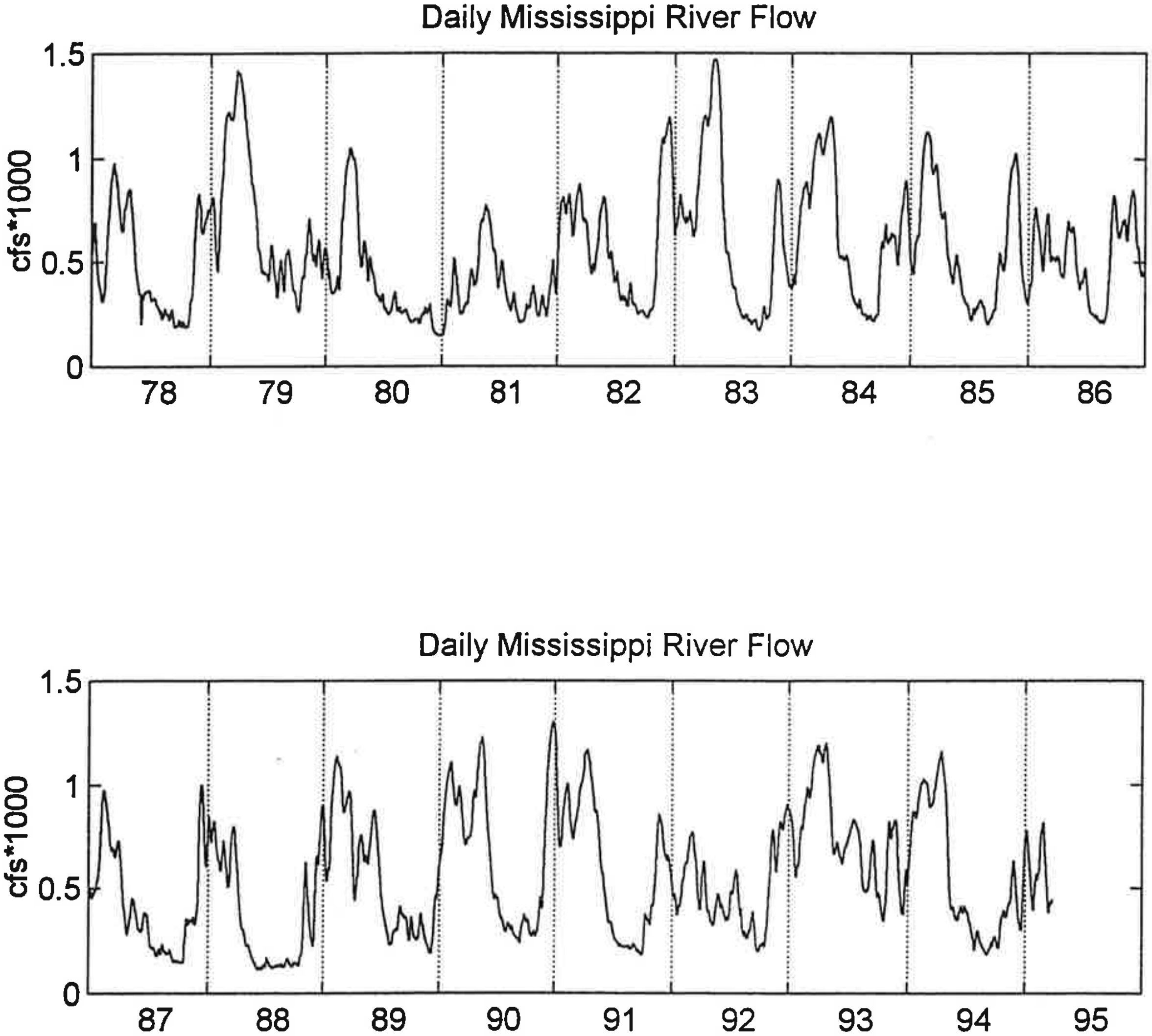

Figure 10. Daily volume of Mississippi River outflow, 1978-1995, data obtained from the Army Corps of Engineers, New Orleans District.

The most interesting and definitive result derived from the trend analysis was not related to specific events, but instead a description of overall decadal scale trends in the region. Long term trend analyses demonstrate no significant trends in surface salinity; and bottom salinity trends are significant at only 2 stations (11%), and these are increasing trends. Surface temperature trends indicated significant increases at 5 station locations, and decreases at none; bottom temperatures increased significantly at 6 station locations and decreased at none. Significantly increasing surface temperatures are occurring at 25% of stations, and significantly increasing bottom temperatures at 33% of stations.

Four of the five stations increasing near surface temperatures are in the offshore region. Physically, stronger stratification due to greater buoyancy flux from the river would indicate higher offshore surface temperatures. The one estuarine station exhibiting an increasing temperature trend is problematic and may simply be due to sampling variability. The higher near bottom temperatures at the offshore stations are spatially coherent and may result from processes associated with the buoyancy flux from the river and the expected stratification increase. An alternative explanation for both the higher salinities at stations 53 and 54 in recent years and the higher temperatures in the region is the interannual variability of shelf interaction with Loop Current rings.

The Loop Current, part of the Gulf Stream system (Stommel, 1965) is arguably the most important oceanographic feature in the Gulf of Mexico (Leipper, 1970). It enters the Gulf through the Yucatan Channel, turns anticyclonically (clockwise), and leaves the Gulf through the Straits of Florida. Aperiodically, it penetrates northward and sheds a large eddy with a diameter measured in hundreds of kilometers. These eddies or rings constitute the oceanographic equivalent of storm systems. They propagate westward across the Gulf and dissipate as they interact with the continental slope of the western Gulf (Smith, 1986; Brooks, 1984). Occasionally, these features propagate into the vicinity of the region of study. Such events have been documented by Huh et al. (1990) and their influences on currents and water properties near the Mississippi delta have been suggested by Ebbesmeyer et al. (1982) and Wiseman and Dinnel (1988). Anecdotal evidence of their occurrence is suggested by reports of exotic (tropical) fish species caught in the region immediately west of the Mississippi River delta (M. Brown, personal communication). The water mass characteristics of these features are warm temperatures and high salinities.

The occurrence of a Loop Current ring in the study area is a relatively rare phenomenon, e.g. Wiseman and Dinnel (1988). The intrusion of such features could bias estimates of long term trends of both temperature and salinity and explain the significance of the trends observed in near-bottom temperature and salinity at offshore stations. We have not yet been able to identify an accurate long-term time series of the occurrence of rings in the region of study. Statistically, though, fronts delineating warm oceanic waters from normal shelf waters are observed in the region at least 2.5% of the time (F. Vukovitch, personal communication). The U. S. Minerals Management Service is funding an ongoing study of the intrusion of such features onto the upper slope and shelf immediately east of the Mississippi River delta and the results of this study should shed additional light on the frequency of events in the region.

B. CLASSIFICATION OF THE PROJECT AREA

The project area is a diverse mixture of Louisiana estuarine and inner continental shelf regimes, extending well into shallow bayou regions in which mean salinities as low as 1-3 ppt were recorded.

1. Temporal and Spatial Patterns

Spatial patterns that prevail in the region of study illustrate the differences between stations in continental shelf and lower and upper estuarine regimes. Mean surface salinity contours over the region of study for the months of January, April, July, and October (winter, spring, summer, and fall) are presented in Figure 11. Generalized lowering of salinity in Barataria Bay as well as in offshore regions by April can be attributed to spring rains and freshwater outflow from streams and rivers. Salinity contours in offshore regions do not parallel the coast, and this may be due to incursions of the freshwater Mississippi River plume. Increases in surface salinity by July,

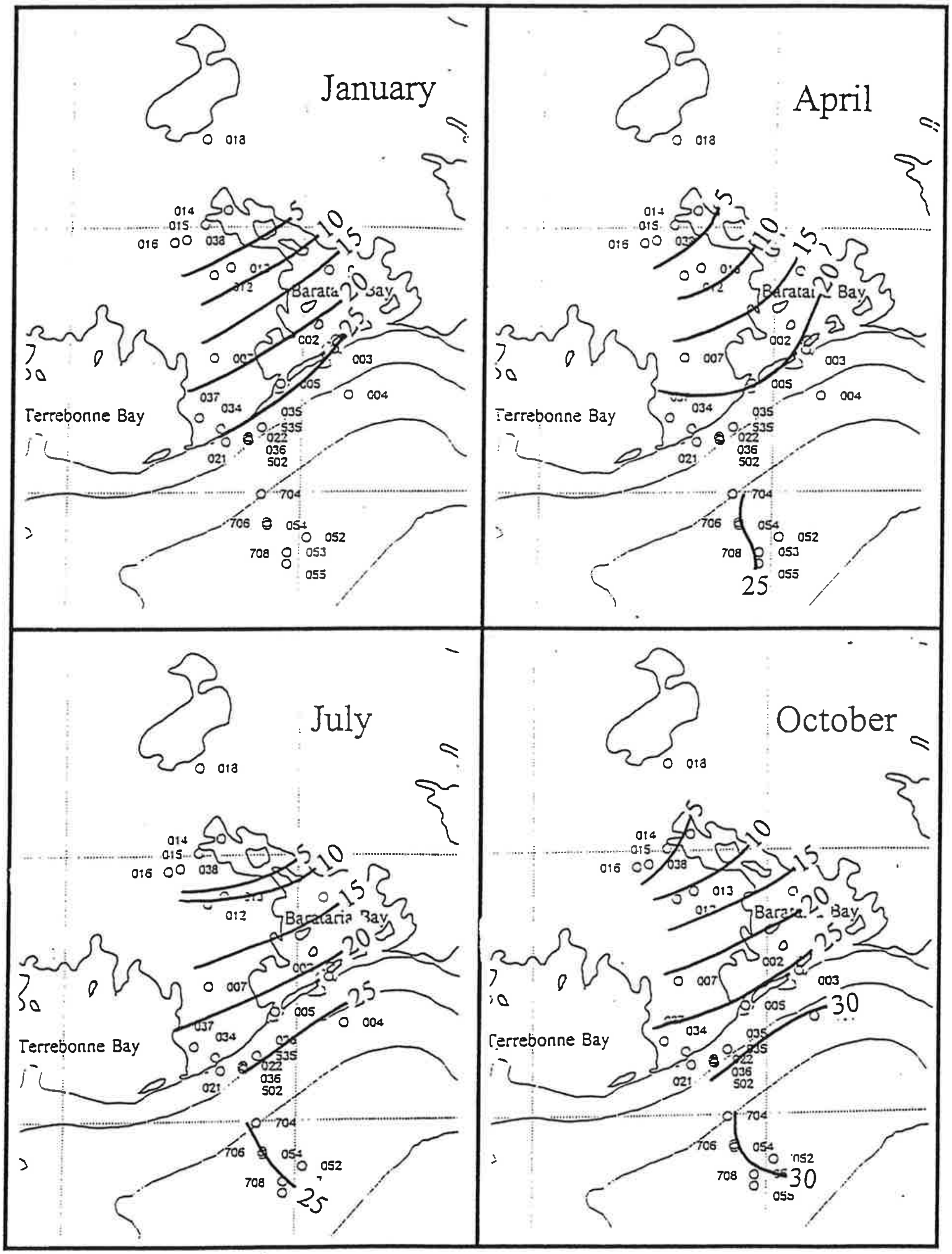

Figure 11. Seasonal surface salinity contours in the study region.

and further increases by October, can be attributed to the combination of reduced Mississippi River discharge, lower rainfall and increased evaporation during the warm months of summer and early fall in this region.

Mean near surface temperature contour plots for spring, summer, fall, and winter seasons in the study area are available in Figure 12. These mean temperatures change from season to season, as is expected due to heat flux through the surface boundary. Contours for spring, summer, and fall suggest the predominance of these boundary effects on near surface temperature means during these seasons, due to the roughly uniform temperatures throughout the study region (especially during the summer) and the relatively large scale of atmospheric thermal variability. Contours for the winter season indicate colder, shallower water in northern portions of the region during the winter. This suggests that the relative influence of surface heat flux during cold air outbreaks drops temperatures more in shallow water than in deep water.

2. Identification of Natural Variability

The effect of Mississippi river outflow is thought to be strong in the region of study, particularly in offshore areas. The time scales at which the river outflow affects local salinity are of interest, and are addressed here by means of squared coherence between weekly mean volume of river outflow and weekly mean salinity times series at the high resolution time series stations, and squared coherence between monthly mean volume of river outflow and monthly means at these stations, or monthly measurements at offshore stations (Appendix F).

The coherence squared represents a correlation coefficient between two time series as a function of time scale. We compare salinity time series and river discharge series using this technique to determine at which scales the river discharge events might influence the local salinities. The river gauging station at Tarbert's Landing is upstream of Baton Rouge. The time required for water measured at Tarbert's Landing to reach the mouth of the river is variable and depends upon river stage. The time lag is shorter at high river stage and longer at low stage. It has been estimated to vary between a few days at high stage and 1.5-2 weeks at low stage. There is

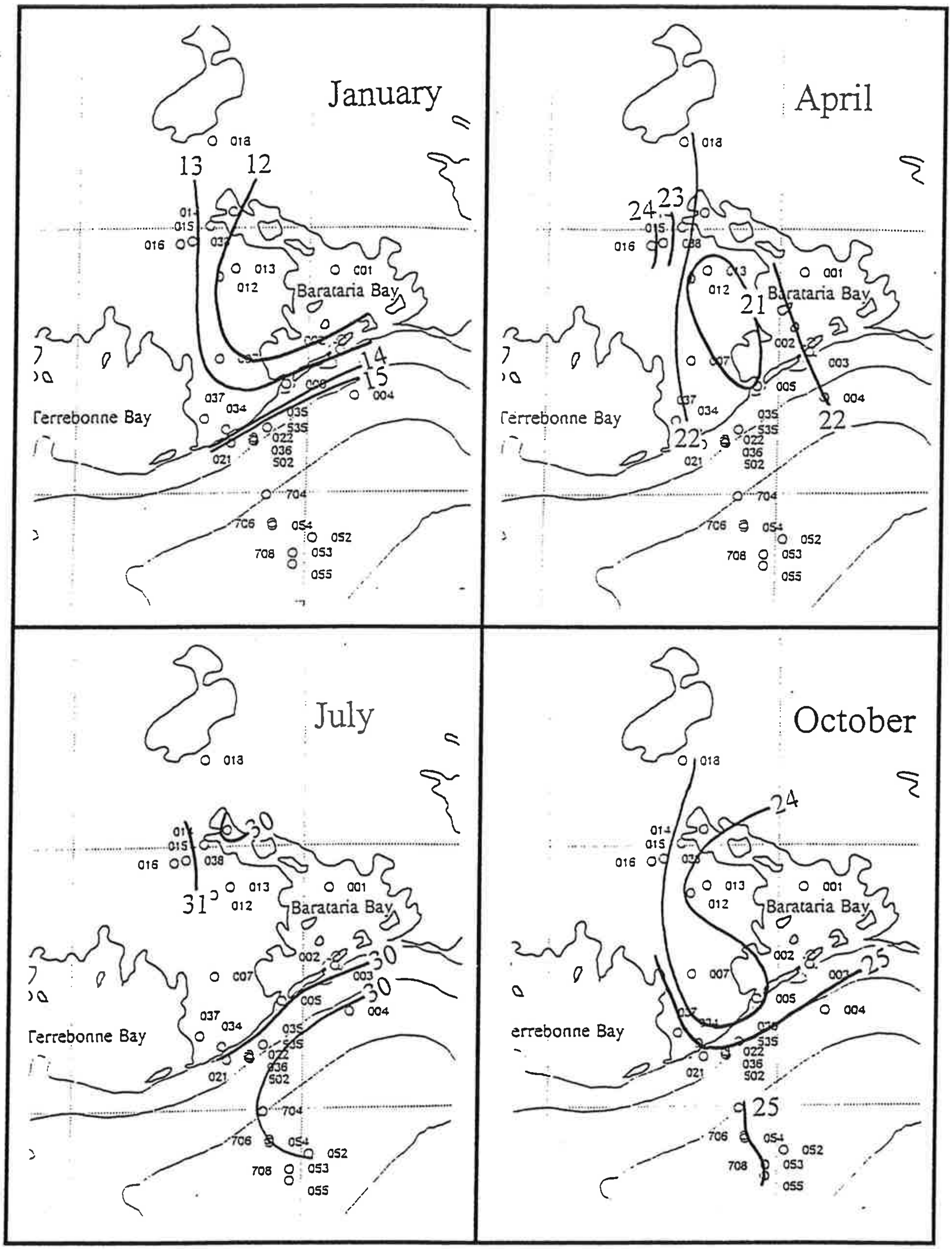

Figure 12. Seasonal surface temperature contours in the study region.

no reliable method for eliminating this level of uncertainty in the available data set, and therefore no effort was made to lag river discharge to account for the run from Tarbert's Landing to the mouth of the river. Consequently, we cannot hope to resolve the phase lag between river discharge and salinity time series to better than a few weeks nor to determine reliable coherence estimates for time scales shorter than a few weeks. Fortunately, most of the variance in river discharge occurs at time scales longer than a few weeks and, consequently, we expect the associated response to occur at similar scales.

Squared coherence estimates are plotted by frequency for each offshore station in Appendix F. It appears that coherence is greatest at annual frequencies, as might be expected due to the substantial seasonal changes that occur in river flow. Coherence of salinity at station 14 (an estuarine station) with river flow was also plotted, and coherence at annual periods at this station appears to be relatively small as is coherence with bottom measurements of salinity at offshore stations. This indicates lesser river influence on salinity at estuarine than at offshore stations, as well as lesser influence of the Mississippi River plume on the bottom than at the top of the water column.

Wind driven mixing of coastal ocean waters can allow the lower salinities of the freshwater plume to penetrate deeper waters. In coastal ocean waters with significant density stratification, such mixing requires relatively greater energy input from wind forcing than is required in less stratified waters. Therefore, in the former case the deeper waters can be isolated to some degree from the influence of the freshwater river plume, and lower coherence of salinity with Mississippi River outflow is to be expected.

Estuarine waters are affected less by the riverine signal than are coastal ocean waters in the study region. This reflects the fact that the influence of the coastal ocean, and thus the freshwater plume, on estuarine waters occurs as they disperse up the estuary from the Gulf. This mixing process will result in reduced coherence with the river discharge as one moves further up-estuary from the source of Mississippi River water.

River outflow is indirectly influenced by cumulative rainfall, especially in upstream areas. The direct influence of heavy local rainfall on local surface salinities is of interest also. Plots of salinity time series at stations 5, 21, 22, 35, 36, 37,52, 53, 54, 55, 502, 704, 706, 708, and others depict a distinct local salinity minimum in late spring, 1991 (Figures B5, B13-B14, B16-B18, B20-B23, B26-B28). This occurred during a time of heavy rainfall in this part of Louisiana. Intense local rainfall influences surface salinities at higher frequencies than the annual. Rain data that lies within the LOOP study region is especially valuable for determining the effect of local rainfall on surface salinity. However, the previously unverified rain data collected by LDWF within the study region appears to be unsuited for this purpose in the present study due to the method of collection, which apparently allowed evaporation to substantially affect cumulative rainfall records, and due to the relatively short time period over which it was collected (1978-1980).

A local maximum in surface salinities appears in 1981 at numerous stations (for example, station 1). The reason for this maximum is unknown, but may be attributable to the dual effect of relatively low Mississippi River discharge and low rainfall in the region at that time.

C. IMPACTS AND POSSIBLE CAUSES

A BACI analysis was performed on the LDWF-LOOP salinity and temperature data from the monthly measurements of the physical hydrography dataset. No statistically significant results were obtained in the analysis for impact of those LOOP activities considered on these variables

The surface salinity results (Table 7) indicate that there were no impacts for any of the events analyzed (none of the interaction terms were significant). The results for the bottom salinity analyses indicate no impacts of the construction, the brine pumping, or the Clovelly Dome oil spills. The offshore data show a significant interaction when considering oil spills, however the oil covariate is not significant. This indicates that there was some sort of an impact over the time period analyzed, but suggests that it cannot be directly attributed to the oil spills.

The temperature results (Table 8) indicate that there were no impacts for any of the events analyzed except the surface temperature at Clovelly Dome which showed a significant oil spill term, indicating that there was a change in surface temperature that was correlated with oil. The temperature for the control class increased from 21.97°C to 22.71°C, and the temperature in the impact class decreased from 23.67°C to 23.56°C. Although these changes are statistically

TABLE 7

RESULTS OF BEFORE:AFTER, CONTROL:IMPACT (BACI) ANALYSES

OF LOOP PHYSICAL HYDROGRAPHY SALINITY DATA.

Listed, for each BACI model is the F value and the probability for (1) the Before:After, (2) the Control:Impact, and (3) the interaction of the Before:After and Control:Impact portions of the model. In the case of the oil spills, the F value and the probability is also given for the oil spill covariate used in the model. Results are given for surface and bottom salinity. Details of the parameters used in the BACI model are listed in Table 2. The symbol nd indicates that there were not enough data points to run the model, and the symbol na indicates the model term was not applicable. Bold face indicates a result significant at the 0.05 level.

Surface Salinity

Type of Impact	Before:After F	Before:After P>F	Control:Impact F	Control:Impact P>F	Interaction F	Interaction P>F	Oil Spill Covariate F	Oil Spill Covariate P>F
Construction	0.695	0.514	1.633	0.302	1.133	0.345	.na	.na
Brine Discharge	1.837	0.186	0.242	0.627	0.506	0.604	.na	.na
Oil Spills								
Clovelly Dome	1.137	0.343	37.807	0.193	4.533	0.016	0.278	0.598
Offshore Terminal 1	2.201	0.325	0.093	0.761	1.320	0.268	1.923	0.166
Offshore Terminal 2	1.170	0.334	**3.161**	**0.044**	1.399	0.233	1.923	0.166

Bottom Salinity

Type of Impact	Before:After F	Before:After P>F	Control:Impact F	Control:Impact P>F	Interaction F	Interaction P>F	Oil Spill Covariate F	Oil Spill Covariate P>F
Construction	.nd	.nd	.nd	.nd	.nd	.nd	.na	.na
Brine Discharge	**5.712**	**0.011**	0.230	0.661	1.047	0.352	.na	.na
Oil Spills								
Clovelly Dome	2.258	0.135	1.379	0.344	0.485	0.492	0.250	0.617
Offshore Terminal 1	0.391	0.682	**13.553**	**0.003**	**5.507**	**0.004**	0.707	0.400
Offshore Terminal 2	0.150	0.862	**4.861**	**0.050**	**3.307**	**0.011**	0.707	0.401

TABLE 8

RESULTS OF BEFORE:AFTER, CONTROL:IMPACT (BACI) ANALYSES

OF LOOP PHYSICAL HYDROGRAPHY TEMPERATURE DATA.

Listed, for each BACI model is the F value and the probability for (1) the Before:After, (2) the Control:Impact, and (3) the interaction of the Before:After and Control:Impact portions of the model. In the case of the oil spills, the F value and the probability is also given for the oil spill covariate used in the model. Results are given for surface and bottom temperature. Details of the parameters used in the BACI model are listed in Table 2. The symbol nd indicates that there were not enough data points to run the model, and the symbol na indicates the model term was not applicable. Bold face indicates a result significant at the 0.05 level.

Surface Temperature

	Before:After		Control:Impact		Interaction		Oil Spill Covariate	
Type of Impact	F	P>F	F	P>F	F	P>F	F	P>F
Construction	2.717	0.089	1.112	0.352	0.869	0.483	.na	.na
Brine Discharge	**4.510**	**0.021**	0.074	0.788	0.025	0.975	.na	.na
Oil Spills								
Clovelly Dome	1.409	0.268	1.481	0.370	0.528	0.590	**7.635**	**0.006**
Offshore Terminal 1	2.124	0.148	1.155	0.283	0.940	0.391	2.240	0.135
Offshore Terminal 1	2.472	0.114	0.799	0.451	0.771	0.544	2.240	0.135

Bottom Temperature

	Before:After		Control:Impact		Interaction		Oil Spill Covariate	
Type of Impact	F	P>F	F	P>F	F	P>F	F	P>F
Construction	.nd	.nd	.nd	.nd	.nd	.nd	.na	.na
Brine Discharge	**4.479**	**0.022**	0.884	0.3519	0.019	0.982	.na	.na
Oil Spills								
Clovelly Dome	.nd	.nd	.nd	.nd	.nd	.nd.	.nd	.nd
Offshore Terminal 1	3.397	0.055	0.061	0.804	0.187	0.830	0.115	0.735
Offshore Terminal 2	**3.731**	**0.044**	0.251	0.778	0.626	0.644	0.115	0.735

significant, they are not ecologically significant (R. E. Turner, personal communication).

Although markedly increased salinities are apparent in the data taken in the immediate proximity of the brine diffuser site during brine disposal, these do not appear to have long-lasting or widespread effects on the physical hydrography of the region or to cause a clear impact on the region, and this is apparent in results from trend analysis and BACI testing.

V. CONCLUSIONS

A. Offshore Hydrography

Temperature-salinity characteristics at offshore stations were similar to available historical information obtained from this region (Wiseman, et al. 1982). Offshore stations 52, 53, 54, 55, 704, 706, and 708 had the most complete physical hydrography record of any offshore stations, and study of the offshore regime focused primarily on these stations. Interannual variability in temperature is less than the intra-annual variability at these offshore stations for near surface, mid-depth, and near bottom records (Figures B20-B23, B26-B35, B45-B48, and B51-B53).

Coherence of surface salinity records at all offshore stations with Mississippi river outflow was high at annual periods (Appendix F). This coherence did not extend to the near bottom salinity records at these stations, except at station 704 where there was some coherence at annual periods for unknown reasons. Phase was consistent with the hypothesis of river forcing primarily contributing to the near annual period response in near surface salinity records in the offshore region.

Tables E1-E4 list the results of trend analyses for a number of stations including the seven offshore stations listed. Significant increasing long term trends in temperature occurred near the bottom at six of these seven stations, and near the surface at four of the seven stations. Near the bottom, significant increasing salinity trends occurred from 1978-1995 at stations 706 and 708, although there were no significant trends in near surface salinity over this time period.

The causes for these significant increasing trends in temperature and salinity in the offshore regime are unknown. It is doubtful that the increasing temperature trends are due to changes in atmospheric climate. The large spatial scales of atmospheric thermal variability would suggest that if this were indeed the case, significant increasing temperature trends would occur at nearshore and estuarine stations, which is not the case.

B. Nearshore Hydrography

Nearshore stations 21, 22, 35, 36, 502, and 535 provided the most complete physical hydrography record of the nearshore stations at which monthly measurements were obtained. The nearshore region was also the location of stations 306, 318, 319, and 335, at which constant recorders measured temperature, salinity, and current speed and direction. These ten stations were the primary focus of study for the nearshore region. Intra-annual variability is larger than interannual temperature and salinity variability in the nearshore regime (Appendices B and D). Temperature-salinity characteristics at nearshore stations were consistent with historical hydrographic findings in the region. Monthly temperature and salinity means and variances were computed for the constant recorder stations, and these were plotted as time series to illustrate seasonal patterns of these moments. Summer heating and winter cooling are reflected in the temperature means at Station 315 illustrated in Figure D1, as are increases in temperature variance during winter months presumably as a response to cold fronts and other storms during that season. Despite gaps in the current meter records, months in which a meaningful monthly mean and variance could be computed were identified and these statistical moments were also plotted as times series (Appendix D). Mean east and north velocities were not statistically different from zero (Tables A12-A13); current velocity was highly variable. Although mean current velocity at stations 306, 318, and 319 was towards the southwest, mean currents were towards the northeast at station 335 (which is further east than stations 306, 318, and 319). The cause for this opposing mean current direction at station 335 is not known, but it is possibly due to bifurcation of the Mississippi River plume as it merges with the Louisiana Coastal Current (Rouse and Coleman, 1976). Salinity records were not long enough to estimate coherence at annual frequencies between salinities at these fixed stations and Mississippi River outflow (Appendix F), though salinities would be expected to respond to annual scale riverine discharge patterns which influence salinity in both offshore and estuarine regimes.

No significant long term trends in salinity or temperature were detected in the nearshore region. Significant temperature increases at stations 318, 319, and 335, and significant salinity increase at station 319 occurred over the relatively brief periods of operation of these stations (Tables E61-E62). However, no significant temperature or salinity trends were observed at the six nearshore stations having very long time series of monthly measurements (Tables E1-E4). Thus, the trends at stations 318, 319, and 335 are attributed to sampling variability rather than to a true long term trend.

BACI impact analyses detected no significant impact on physical hydrography data sets in this region that could be attributed to LOOP activities, including construction and brine pumping. It is noted, though, that the sled data (LDWF, 1995) which was not analyzed in this report, clearly demonstrated the local increase of near-bottom salinities due to brine pumping.

C. Hydrography in the Lower Estuary

The lower estuarine regime includes marsh stations such as station 34, 37, and 7, and station 5 which is located in Caminada Pass. Constant recorder stations 315 (Grand Terre), 317 (St. Mary's Point), 322 (Caminada Pass), and 323(Lake Palourde and Bay Macoin Channel) are also located in the lower estuary. These eight stations provided the most complete physical hydrography time series of the lower estuarine region, and study of this area centered on their records. Seasonal variability in temperature in the lower estuary is consistent with historical observations for this region. Intra-annual variability is larger than interannual variability in this region, as has been described above for the offshore and nearshore regions.

No significant trends in temperature or salinity from 1978-1995 were detected by seasonal Kendall tau tests for trend at stations 5, 7, 34, and 37. There were no significant long term trends in temperature or salinity at these stations before or after heavy brine disposal associated with LOOP construction in 1980-1982. Significant trends in temperature data were detected at fixed station stations 315 and 317(increasing), and 323(decreasing). The source of the decreasing trend is not clear but is probably due to the short record. The lack of spatial coherence of increasing trends is disconcerting. The logical source of a temperature trend is air/sea interaction. Such processes have large spatial scales and should affect all estuarine stations. While the source of the apparent temperature increase at stations 315 and 317 is unresolved, it is consistent with the trends observed offshore. Significant trends of decreasing salinity existed at stations 317 and 323.

Stations 315 and 317 have very long temperature and salinity records. However, the salinity trend at station 317 was not accompanied by a similarly decreasing significant salinity trend at station 315. This decrease at station 317 may be in response to increased precipitation upstream of St. Mary's Point from 1978-1995, although precipitation data sufficiently near this location to test this hypothesis are not available. Increased discharge from river diversions into Barataria Basin could also lead to decreasing salinity trends at St. Mary's Point, although there is not sufficient data available to suggest that this is the case. Although significant decreasing salinity trends were not observed at Grand Terre, it is possible that changes in Mississippi River outflow volume could still be responsible for the decreasing salinity at St. Mary's point. This would assume a major route of freshwater encroachment into Barataria Bay by the Mississippi River plume that does not pass station 315, e.g. through Pass Abel or Quatre Bayous Pass.

No significant impact of LOOP activities on temperatures or salinities in the lower estuary was detected by BACI analyses.

D. Hydrography in the Upper Estuary

Upper estuary stations included stations 12, 13, 14, 15, 16, 18, and 38, at which monthly samples were taken, and 320, 321, 324, 325, and 326 which were fixed recorder stations. These stations were taken to represent upper estuarine conditions. Although very little historical temperature or salinity data is available for the upper estuary region, the low salinities and seasonal variability appear typical when compared with sparse previous data from this region.

There were no significant trends in salinity or temperature for the period from 1978-1995, except for an anomalous trend of increasing surface temperature at station 16. The reasons for this trend are unknown. We have no hypothesis for a possible mechanism behind this trend, beyond normal sampling variability. This temperature trend at station 16 is increasing, as are the other significant temperature trends that were all identified in areas further seaward.

BACI testing detected no significant impact of LOOP construction or oil spills on temperature or salinity at Clovelly Dome in the upper estuary.

E. Overall Conclusions

Construction of the Louisiana Offshore Oil Port (LOOP) facilities and brine disposal operations did not clearly impact the physical hydrography in the study area. Long term trends in temperature and salinity time series do not appear to have been affected by the major 1980-1982 brine discharges, or by the one year cessation of brine discharge in 1990.

The long term characterization of regional physical hydrography presented herein contributes to an understanding of the regional physical hydrography of Barataria Bay and nearby estuarine and offshore locations. As such it will provide a useful baseline from which to assess any alleged environmental effects of future LOOP activities.

VI. REFERENCES

1. Barrett, B. B., 1971, Cooperative Gulf of Mexico estuarine inventory and study, Louisiana, phase II, hydrology, and phase III, sedimentology, Louisiana Wild Life and Fisheries Commission, New Orleans, LA, 191 pp.

2. Brooks, D. A., 1984, Current and hydrographic variability in the northwestern Gulf of Mexico, J. Geophys. Res. 89, pp. 8022-8032.

3. Byrne, P., Borengasser, M., Grew, A., Miller, R. A., Smith, B. L. Jr., and Wax, C., 1976, Barataria basin: hydrologic and climatologic processes, Sea Grant Publ. LSU-T-76-010, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA, 176 pp.

4. Cochrane, J. D., and Kelly, F. J., 1986, Low-frequency circulation on the Texas-Louisiana continental shelf, J. Geophys. Res. 91, 10645-10659.

5. Condrey, R, Kemp, P., Visser, J., Gosselink, J., Lindstedt, J., Melancon, E. Jr., Peterson, G., and Thompson, B., Characterization of the current status, trends, and probable causes of change in living resources in the Barataria-Terrebonne estuarine system, BTNEP Publ. No. 21, Barataria-Terrebonne National Estuarine Program, Thibodaux, Louisiana.

6. Csanady, G. T., 1981, Circulation in the coastal ocean, Advances in Geophysics 23, 101-183.

7. Daddio, E., Wiseman, W. J. Jr., and Murray, S. P., 1978, Inertial currents over the inner shelf near 30 N., J. Phys. Oceanogr. 8(4), 728-733.

8. Dinnel, S. P., and Wiseman, W. J. Jr., 1986, Fresh water on the Louisiana and Texas shelves. Cont. Shelf Res. 6(6), pp. 765-784.

9. Dinnel, S. P., Wiseman, W. J. Jr., and Rouse, L. J. Jr., 1997, Coastal currents in the northern Gulf of Mexico. OCS Study MMS 97-0005, U. S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 113 pp.

10. Ebbesmeyer, C. C., Williams, G. N., Hamilton, R. C., Abbott, C. E., Collipp, B. G., and McFarlane, C. F., 1982, Strong persistent currents observed at depth off the Mississippi River Delta, Proc. 14th Int. Offshore Tech. Conf., Houston, pp. 259-267.

11. Gill, A. E., 1982, Atmosphere-Ocean Dynamics, Academic Press, San Diego, 662 pp.

12. Gosselink, J. G., Miller, R. R., Hood, M., and Bahr, L. M. Jr. 1976, Louisiana Offshore Oil Port Environmental Baseline Study, Report prepared for LOOP, INC, New Orleans, Louisiana.

13. Hacker, S., 1973, Transport phenomena in estuaries, Louisiana State University, Dept. Chem. Eng., Ph.D. Dissertation, 335 pp.

14. Hirsch, R. M., J. R. Slack, and R. A. Smith, 1982, Techniques of trend analysis for monthly water quality data, Water Res. Research Vol. 18, No. 1, pp. 107-121.

15. Hitchcock, G.L., Wiseman, W. J. Jr., Boicourt, W. C., Mariano, A. J., Walker, N., Nelson, T. A., and Ryan, E., 1997, Property fields in an effluent plume of the Mississippi River. J. Mar. Sys. 12:109-126.

16. Huh, O. K., and Schaudt, K. J., 1990, Satellite imagery tracks currents in Gulf of Mexico, Oil & Gas Journal, May 7, pp. 70-76.

17. Jochens, A. E., and Nowlin, W. D., eds., 1994: Texas-Louisiana shelf circulation and transport processes study: year 1, annual report, volume II: Technical Report. MMS 94-0030, U. S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA, 207 pp.

18. Kendall, M. G., 1938, A new measure of rank correlation, Biometrika, Vol. 30, pp. 81-93.

19. Kjerfve, B., 1973, Dynamics of the water surface in a bar-built estuary, Louisiana State University, Dept. Mar. Sci., Ph.D. Dissertation, 91 pp.

20. Kjerfve, B., 1975, Tide and fair-weather wind effects in a bar-built Louisiana estuary, in Estuarine Res., Vol. 11, Academic Press, New York, pp. 47-62.

21. Leipper, D. F., 1970, A sequence of current patterns in the Gulf of Mexico, J. Geophys. Res. 75, pp. 637-657.

22. Louisiana Department of Wildlife and Fisheries, 1995, Environmental monitoring of the Louisiana Offshore Oil Port (LOOP, Inc.) 1978-1994, Brine Monitoring, Part 1. Draft report prepared for LOTA Program Review Committee, 58 pp.

23. Marmer, H. A., 1954, Tides and sea level in the Gulf of Mexico, Fish. Bull. 89, 101-118.

24. McKee, B., Wiseman, W. J. Jr., and Inoue, M., 1994, Salt flux and sediment residence times in a bar-built estuary, in Mixing Processes in Estuaries and Coastal Seas, C. Pattiaratchi (ed.), AGU, Washington, D.C., pp. 157-170.

25. McKenzie, L. C. III, Wascom, M. W., Keithly, W. R., Emmer, R. E., Hudnall, W. H., Johnson, M. T. C., Niami, F., and Touchet, B. A., 1995, Land use and socioeconomic status and trends in the Barataria-Terrebonne estuarine system, BTNEP Publ. No. 23, Barataria-Terrebonne National Estuarine Program, Thibodaux, Louisiana.

26. NMFS, 1997, Personal communication from the National Marine Fisheries Service, Fisheries Statistics and Economics Division (http://remora.ssp.nmfs.gov)

27. Pritchard, D. W., 1967, Observations of circulation in coastal plain estuaries, in Estuaries, Lauff, G. H. (ed.), Am. Assoc. Adv. Sci., pp. 37-44.

28. Pritchard, D. W., and Bunce, R. E., 1959, Physical and chemical hydrography of the Magothy River, Tech. Rep. XVII, Ref. 59-2, Chesapeake Bay Inst., Johns Hopkins University, Baltimore.

29. Rabalais, N. N., Turner, R. E., Wiseman, W. J. Jr., and Boesch, D. F., 1991, A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988, in Modern and Ancient Continental Shelf Anoxia, R. V. Tyson and T. H. Pearson (eds.), Geological Society Special Publication No. 58, pp. 35-47.

30. Rouse, L. J. Jr., 1997, Circulation and hydrographic structure in the vicinity of the Mississippi River Delta, in an observational study of the Mississippi-Atchafalaya coastal plume, U. S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, pp. 121-138.

31. Rouse, L. J. Jr., and Coleman, J. M., 1976, Circulation observations in the Louisiana Bight using LANDSAT imagery, Rem. Sens. Environ. 5, pp. 55-66.

32. SAS, 1990a, SAS Procedures Guide, Version 6, Third Edition. SAS Institute, Inc., Cary, North Carolina. 705 pp.

33. SAS, 1990b, SAS Language Reference, Version 6, First Edition. SAS Institute, Inc., Cary, North Carolina. 1042 pp.

34. SAS, 1990c, SAS/Graph Software Reference, Version 6 First Edition, Volume 1. SAS Institute, Inc., Cary, North Carolina. 1341 pp.

35. SAS, 1990d, SAS/Graph Software Reference, Version 6 First Edition, Volume 2. SAS Institute, Inc., Cary, North Carolina. 605 pp.

36. Sasser, C. E., Gosselink, J. G., Peterson, G. W., Heikamp, A. J. Jr., and Webb, J. C., 1982, Environmental management analysis of the Louisiana Offshore Oilport, Wetlands Vol. 2, pp. 249-261.

37. Schroeder, W. W., and Wiseman, W. J. Jr., 1986, Low-frequency shelf-estuarine exchange processes in Mobile Bayand other estuarine systems on the northern Gulf of Mexico, in Estuarine Variability, D. Wolfe (ed.), Academic Press, New York, pp. 355-367.

38. Smith, D. C., 1986, Numerical study of Loop Current eddy interaction with topography in the western Gulf of Mexico, J. Phys. Oceanogr. 16, pp. 1260-1272.

39. Stommel, H. M., 1965, The Gulf Stream: A Physical and Dynamical Description, University of California Press, Berkeley, 248 pp.

40. Temple, R. F., Harrington, D. L., and Martin, J. A., 1977, Monthly temperature and salinity measurements of continental shelf waters of the north-western Gulf of Mexico, 1963-1965, NOAA Rep., NMFS, SSFR-707, 26 pp.

41. Turner, R. E., and Allen, R., 1982, Bottom water oxygen concentration in the Mississippis River Delta Bight, Contrib. Mar. Sci. 25, 161-172.

42. Underwood, A. J., 1994, On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecol. Applic. Vol. 4, pp. 3-15.

43. Von Arx, 1949, unpublished report to the Freeport Sulphur Company.

44. Walker, N. D., 1996, Satellite assessment of Mississippi River plume variability: causes and predictability. Rem Sens. Environ. 58, pp. 21-35.

45. Wax, C. L., Borengasser, M. J., and Muller, R. A., 1978, Barataria Basin: synoptic weather types and environmental responses, Center for Wetlands Resources, Louisiana State University, Sea Grant pub. no. LSU-T-78-001, 60 pp.

46. Weisberg, S., Applied Linear Regression, 1985, Wiley, New York, Chapter 1, pp. 1-27.

47. Whitaker, R. E., 1971, Seasonal variations of steric and recorded sea level of the Gulf of Mexico. M.S. thesis, Texas A&M University, College Station, 111 pp.

48. Wiseman, W. J. Jr., Bane, J. M., Murray, S. P., and Tubman, M. W., 1975a, Small-scale temperature and salinity structure west of the Mississippi River Delta, in Memoires de la societe royale des sciences de Liege X, pp. 277-285.

49. Wiseman, W. J. Jr., and Dinnel, S. P., 1988, Shelf currents near the mouth of the Mississippi River, J. Phys. Oceanogr. 18, pp. 1287-1291.

50. Wiseman, W. J. Jr., and Inoue, M., 1993, Salinity variations in two Louisiana estuaries, Coastal Zone '93, Proceedings of the eighth symposium on coastal and ocean management, Magoon, O. T., Wilson, W. S., Converse, H., and Tobin, L. T. (eds.), Vol. 1, pp. 1230-1242.

51. Wiseman, W. J. Jr., and F. J. Kelly, 1994, Salinity variability within the Louisiana Coastal Current during the 1982 flood season. Estuaries 17(4):732-739, 1994.

52. Wiseman, W. J. Jr., Murray, S. P., Bane, J. M., and Tubman, M. W., 1975b, Offshore physical oceanography, in Environmental Assessment of a Louisiana Offshore Oil Port and Appertinent Storage and Pipeline Facilities, Vol. II, Gosselink, J. G., Miller, R. R., Hood, M., and Bahr, L. M. Jr. (eds.), Louisiana Offshore Oil Port, Inc., pp. 1-162.

53. Wiseman, W. J. Jr., Murray, S. P., Bane, J. M., and Tubman, M. W., 1982, Physical environment of the Louisiana Bight, Contrib. Mar. Sci. 25, pp. 85-90.

54. Wiseman, W. J. Jr., and Swenson, E. M., 1989, Modelling the effects of produced water discharges on estuarine salinity, in Environmental Impact of Produced Water Discharges in Coastal Louisiana, Boesch, D. F. and Rabalais, N. N (eds.), Prepared by the Louisiana Universities Marine Consortium in collaboration with Louisiana State University and A&M College and Aero-Data Corporation, pp. 23-54.

55. Wiseman, W. J. Jr., Swenson, E. M., and Kelly, F. J., 1990a, Control of estuarine salinities by coastal ocean salinity, in Coastal and Estuarine Studies, Vol. 38, R. T. Cheng (ed.), Springer-Verlag, New York, pp. 184-193.

56. Wiseman, W. J. Jr., Swenson, E. M., and Power, J., 1990b, Salinity trends in Louisiana estuaries. Estuaries Vol. 13, No. 3, pp. 265-271.

57. Wiseman, W. J. Jr., Rabalais, N. N., Turner, R. E., Dinnel, S. P., and MacNaughton, A., 1997, Seasonal and interannual variability within the Louisiana coastal current: stratification and hypoxia. J. Mar. Sys. Vol. 12, pp. 237-248.

APPENDIX A

TABLES OF TEMPERATURE AND SALINITY STATISTICS

TABLE A1

TEMPERATURE STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

SURFACE SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in °C. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
1	1.83	0.30	22.374	6.688	31.500	10.800	31
2	2.07	0.30	22.545	7.041	32.000	7.500	75
3	2.54	0.30	22.684	6.835	32.700	9.900	74
4	11.82	0.30	23.359	6.357	32.400	10.900	64
5	4.10	0.29	22.911	6.405	33.000	7.900	209
6	2.19	0.30	22.485	7.270	32.600	8.000	46
7	1.64	0.29	22.597	6.878	32.500	5.300	206
8	1.67	0.30	23.021	7.351	34.100	7.900	60
9	2.00	0.30	23.252	7.140	36.500	8.900	44
10	2.04	0.32	22.781	7.122	32.900	7.500	56
11	2.62	0.30	22.450	6.797	34.300	10.300	38
12	1.68	0.29	22.366	7.014	32.200	5.570	130
13	1.52	0.29	22.700	7.213	32.900	5.600	181
14	1.91	0.29	21.896	7.084	32.500	2.100	203
15	1.82	0.30	22.354	7.125	33.100	5.700	203
16	2.22	0.29	23.584	7.007	34.100	6.900	178
17	1.57	0.30	21.954	7.406	32.100	9.200	41
18	3.28	0.30	22.494	6.899	32.800	8.900	197
19	1.92	0.30	21.945	7.695	33.300	8.500	40
21	7.87	0.42	23.018	5.587	31.500	9.100	196
22	10.51	0.40	23.209	5.500	31.500	9.900	193
31	3.29	0.30	22.502	6.146	30.800	9.100	41
32	2.40	0.30	22.984	6.425	36.100	9.800	32
33	2.80	0.30	24.476	6.406	37.700	12.900	34
34	1.76	0.28	23.163	7.060	34.500	6.400	196
35	10.49	0.44	23.124	5.397	32.200	12.100	188
36	10.86	0.44	23.456	5.408	31.600	10.000	181
37	3.21	0.34	23.463	6.291	32.600	9.000	181
38	1.84	0.30	23.635	6.961	34.400	6.100	185
39	1.71	0.29	24.408	6.461	33.940	10.700	115
40	1.72	0.28	23.928	6.548	33.090	8.000	51
52	32.98	0.43	23.448	5.457	31.250	11.900	156
53	32.98	0.45	23.548	5.411	31.500	12.800	162
54	26.93	0.50	23.799	5.474	31.700	12.200	156
55	33.90	0.44	23.527	5.363	31.300	12.000	154
407	1.33	0.28	22.125	7.501	33.600	2.900	41

(Table A1, cont.)

435	9.63	0.39	23.447	5.451	32.600	12.200	64
461	0.91	0.29	22.654	7.288	33.100	3.100	40
462	0.91	0.27	21.905	7.588	32.200	2.900	44
463	1.73	0.27	23.610	6.940	32.600	9.900	38
464	1.96	0.27	22.400	7.083	33.100	9.820	44
473	9.38	0.37	23.475	5.509	32.950	10.300	64
474	9.49	0.38	23.450	5.567	33.250	10.800	63
475	9.58	0.40	23.624	5.500	33.400	10.500	65
481	31.88	0.44	23.662	5.267	31.600	14.600	63
482	33.01	0.37	23.757	5.157	31.900	15.500	60
484	31.69	0.42	23.595	5.435	31.200	12.600	61
500	10.67	0.30	23.356	5.580	31.100	14.300	25
501	10.67	0.30	23.548	5.439	31.100	14.700	25
502	10.73	0.41	23.422	5.492	31.700	12.600	162
505	10.67	0.30	23.972	5.442	31.700	15.200	25
506	10.67	0.30	24.148	5.471	32.200	15.200	25
507	10.67	0.30	23.515	5.473	32.100	13.700	55
535	11.09	0.42	23.322	5.677	31.630	12.900	129
601	1.64	0.30	26.443	5.040	33.900	12.500	30
602	1.00	0.30	25.388	6.135	33.700	11.600	38
604	0.68	0.27	25.287	6.196	32.650	11.900	34
605	0.53	0.29	25.919	5.795	33.200	12.600	31
607	1.71	0.31	25.533	5.526	34.500	12.200	36
608	1.24	0.31	25.093	5.939	33.190	11.600	38
609	0.88	0.29	25.144	6.210	33.200	11.300	39
610	1.38	0.28	24.068	6.302	33.070	10.700	47
611	1.55	0.30	23.987	6.010	32.170	10.700	38
612	0.97	0.28	24.338	6.674	33.500	9.900	33
613	1.11	0.27	23.289	6.439	31.800	8.800	25
614	0.48	0.31	22.897	6.021	32.400	10.800	32
615	0.58	0.29	22.276	6.962	32.600	5.700	33
616	0.72	0.31	23.689	5.339	32.900	11.700	27
617	1.08	0.27	23.338	5.920	31.800	12.500	39
618	1.17	0.28	22.736	5.875	31.200	11.200	44
619	1.74	0.28	22.970	5.675	32.110	12.300	39
620	1.00	0.29	23.115	5.723	31.320	11.840	34
621	1.09	0.29	23.345	5.808	32.090	13.000	33
622	0.58	0.29	23.945	6.750	46.200	12.900	35
623	0.84	0.28	25.597	6.135	33.890	12.700	33
624	0.64	0.26	23.665	6.598	32.400	9.900	33
625	0.89	0.27	23.530	6.650	32.900	7.300	30
630	0.45	0.29	24.916	5.681	34.500	11.000	23
701	10.17	0.30	25.356	4.700	32.600	17.200	36
703	15.78	0.50	23.950	5.230	31.500	14.400	85
704	19.55	0.42	23.789	5.330	31.600	12.270	155
706	25.94	0.43	23.617	5.161	31.500	13.400	158
708	32.13	0.47	23.732	5.174	31.130	13.300	154
711	33.18	0.30	24.823	4.990	31.200	16.500	22

(Table A1, cont.)

713	27.31	0.30	25.087	4.927	30.900	16.100	23
715	21.81	0.30	24.468	5.155	30.700	16.000	25
717	15.41	0.30	24.368	5.184	30.700	16.200	25
719	9.69	0.30	24.432	5.744	31.000	11.200	25
857	10.55	0.65	25.639	3.204	31.040	19.690	25

TABLE A2

TEMPERATURE STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

MID-DEPTH SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in °C. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
52	32.98	16.42	23.302	3.825	30.500	13.800	156
53	32.98	16.45	23.373	3.775	30.500	14.000	162
54	26.93	13.55	23.337	4.066	30.700	13.800	156
55	33.90	16.82	23.335	3.667	29.800	13.900	153
481	31.13	15.49	23.103	3.598	29.600	16.500	47
482	31.49	15.70	23.309	3.747	30.100	16.300	47
484	30.85	15.41	23.302	3.501	29.990	16.600	46
500	10.67	5.18	23.096	5.350	30.400	14.300	25
501	10.67	5.18	23.420	5.520	31.000	14.500	25
502	10.62	5.19	23.567	5.175	31.300	14.700	27
505	10.67	5.18	23.392	5.153	30.600	14.500	25
506	10.67	5.18	23.256	5.071	30.700	14.400	25
507	10.67	5.18	23.550	5.165	30.800	14.700	26
535	10.40	5.16	24.169	4.865	31.300	14.500	21
703	15.76	7.78	23.784	4.736	30.700	15.400	81
704	19.50	9.74	23.276	4.398	30.900	14.500	153
706	25.87	12.99	23.263	4.019	31.000	14.700	149
708	32.11	16.05	23.505	3.618	30.900	15.100	151
713	27.30	13.57	24.471	4.120	29.500	16.900	21
715	21.81	10.96	23.852	4.655	29.600	16.300	25
717	15.41	7.96	24.092	4.520	30.300	16.300	25

TABLE A3

TEMPERATURE STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

BOTTOM SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in °C. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
4	12.26	12.26	23.091	4.617	29.900	15.600	22
5	4.11	4.11	22.820	6.254	32.900	7.700	204
18	3.30	3.29	22.408	6.780	32.600	8.500	168
21	7.87	7.87	22.793	4.960	31.200	11.200	196
22	10.51	10.51	22.661	4.601	30.900	12.300	193
35	10.49	10.50	22.737	4.489	31.900	12.500	189
36	10.86	10.86	22.675	4.429	30.800	11.800	181
37	3.19	3.05	23.303	6.236	32.400	8.600	177
38	1.84	1.83	22.990	6.577	33.400	6.100	178
52	32.98	32.97	22.593	2.750	31.600	15.600	156
53	32.98	32.98	22.441	2.676	29.800	15.500	161
54	26.93	27.01	22.781	3.042	30.100	14.100	156
55	33.90	33.89	22.512	2.698	30.000	15.700	153
407	1.37	1.39	21.941	7.305	33.200	2.900	61
435	10.30	10.51	22.656	4.345	30.300	15.800	58
461	1.08	1.04	22.289	7.533	32.900	3.100	51
462	.93	.93	23.122	11.198	91.200	2.900	63
463	1.67	1.58	23.146	7.326	33.200	6.800	57
464	2.10	2.18	22.072	7.663	32.400	3.000	56
473	9.62	9.58	22.608	4.281	30.900	15.200	61
474	9.75	9.63	22.582	4.301	30.400	15.700	60
475	9.84	9.79	22.638	4.322	30.600	15.800	61
481	33.44	33.58	21.957	2.185	27.700	17.900	58
482	33.80	33.81	21.649	3.387	28.500	2.100	58
484	33.39	33.47	21.831	2.128	26.200	17.100	56
500	10.67	10.67	23.040	4.798	30.400	15.600	25
501	10.67	10.67	23.192	4.664	29.400	15.500	25
502	10.73	10.73	22.832	4.233	30.800	13.800	162
505	10.67	10.67	23.004	4.540	30.300	15.000	25
506	10.67	10.67	23.108	4.602	30.400	15.800	25
507	10.67	10.67	22.549	4.230	30.300	14.000	55
535	11.14	10.40	22.610	4.343	29.800	13.800	128
602	1.13	1.20	24.700	5.332	33.940	16.290	23
607	1.67	1.59	24.435	5.904	35.900	14.860	25
608	1.22	1.19	23.662	5.908	32.000	12.280	24
609	.86	.85	22.583	6.770	33.100	10.670	22

(Table A3, cont.)

610	1.34	1.34	23.525	6.335	31.200	12.220	23
611	1.51	1.51	23.255	5.727	31.500	12.790	32
615	.49	.49	23.100	6.571	32.490	8.580	22
617	1.02	.99	21.597	7.195	31.000	8.950	23
618	1.35	1.33	21.897	6.538	31.000	11.500	30
619	1.42	1.42	21.530	6.376	30.970	9.870	25
620	.82	.83	21.794	6.379	31.300	9.620	31
621	.61	.66	21.864	6.317	30.400	9.300	24
701	10.17	7.68	24.544	3.990	30.900	17.100	36
703	15.79	16.05	23.225	3.538	30.800	16.300	84
704	19.55	19.65	22.927	3.138	30.500	14.500	155
706	25.93	25.69	22.834	2.776	29.800	16.700	157
708	32.13	32.16	22.665	2.639	31.400	16.700	155
713	27.31	27.24	22.968	2.547	27.100	18.300	22
715	22.65	22.65	23.461	2.995	28.000	18.600	23
717	16.46	16.44	24.200	3.747	29.000	17.700	21
719	9.69	9.33	23.620	4.811	31.000	16.000	25
857	10.55	10.19	24.228	3.171	30.330	19.380	25

TABLE A4

SALINITY STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

SURFACE SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
1	1.83	0.30	12.471	4.840	25.300	2.200	31
2	2.07	0.30	20.133	6.779	37.000	5.600	75
3	2.54	0.30	21.024	7.098	37.100	5.900	74
4	11.82	0.30	24.086	6.391	38.100	10.200	64
5	4.10	0.29	21.797	6.076	35.900	8.110	205
6	2.19	0.30	21.726	5.341	30.100	10.200	43
7	1.64	0.29	17.424	5.020	29.200	4.900	200
8	1.67	0.30	18.248	5.140	29.500	6.900	57
9	2.00	0.30	18.062	5.231	29.400	8.700	40
10	2.04	0.32	17.811	4.634	27.000	7.700	56
11	2.62	0.30	10.800	5.904	24.300	0.400	36
12	1.68	0.29	9.587	4.757	21.900	0.700	127
13	1.52	0.29	8.710	4.889	23.100	0.500	177
14	1.91	0.29	3.782	4.072	18.600	0.100	197
15	1.82	0.30	3.450	2.974	15.700	0.100	201
16	2.22	0.29	2.035	2.400	12.800	0.100	176
17	1.57	0.30	2.428	2.370	11.600	0.100	43
18	3.28	0.30	1.080	1.629	9.100	0.100	183
19	1.92	0.30	2.071	1.777	6.300	0.200	42
21	7.87	0.42	25.821	5.184	36.300	11.100	188
22	10.51	0.40	26.210	5.154	36.000	11.000	180
31	3.29	0.30	25.666	6.137	36.900	10.900	38
32	2.40	0.30	19.966	4.980	28.200	10.000	32
33	2.80	0.30	23.856	4.836	31.900	11.900	34
34	1.76	0.28	23.932	5.043	33.900	1.400	184
35	10.49	0.44	25.889	5.338	35.700	5.480	182
36	10.86	0.44	26.037	5.182	36.100	11.600	176
37	3.21	0.34	24.532	4.509	32.870	1.910	171
38	1.84	0.30	2.946	2.478	12.900	0.100	182
39	1.71	0.29	2.725	2.267	11.700	0.160	115
40	1.72	0.28	10.382	4.679	19.400	1.600	50
52	32.98	0.43	26.019	5.616	36.670	0.990	152
53	32.98	0.45	26.759	5.348	39.300	9.200	158
54	26.93	0.50	26.173	5.145	37.140	9.100	151
55	33.90	0.44	26.745	5.293	40.510	9.700	151
407	1.33	0.28	17.529	5.077	27.400	5.200	41

(Table A4, cont.)

435	9.63	0.39	25.275	5.329	35.300	13.400	64
461	0.91	0.29	2.321	2.106	8.500	0.100	40
462	0.91	0.27	16.968	5.355	25.900	1.800	44
463	1.73	0.27	3.382	4.703	28.000	0.100	38
464	1.96	0.27	2.964	2.640	11.800	0.100	41
473	9.38	0.37	24.782	5.205	33.900	11.900	64
474	9.49	0.38	24.687	5.336	34.300	12.600	63
475	9.58	0.40	24.835	5.241	34.500	11.900	65
481	31.88	0.44	26.600	5.724	36.800	9.400	64
482	33.01	0.37	25.837	6.105	36.100	9.290	63
484	31.69	0.42	27.121	5.292	35.600	12.100	60
500	10.67	0.30	25.648	5.549	32.000	8.200	25
501	10.67	0.30	26.052	5.225	31.900	8.600	25
502	10.73	0.41	25.611	5.358	35.100	7.800	161
505	10.67	0.30	26.800	5.254	32.500	9.500	25
506	10.67	0.30	26.400	5.384	32.200	9.500	25
507	10.67	0.30	26.446	5.385	33.300	8.800	54
535	11.09	0.42	25.378	5.585	40.920	8.200	126
601	1.64	0.30	2.685	2.529	8.800	0.200	27
602	1.00	0.30	2.713	2.289	11.700	0.300	36
604	0.68	0.27	3.323	2.553	11.300	0.200	32
605	0.53	0.29	3.244	2.401	12.500	0.200	31
607	1.71	0.31	2.864	2.419	12.700	0.200	34
608	1.24	0.31	3.003	2.443	12.300	0.200	37
609	0.88	0.29	3.156	2.586	11.500	0.200	38
610	1.38	0.28	3.447	3.031	13.700	0.200	46
611	1.55	0.30	4.248	3.870	13.600	0.210	32
612	0.97	0.28	4.898	3.920	14.600	0.400	29
613	1.11	0.27	9.178	4.278	21.900	0.700	24
614	0.48	0.31	22.702	4.829	31.800	11.200	32
615	0.58	0.29	22.151	6.356	30.400	0.600	33
616	0.72	0.31	22.225	5.697	30.300	9.800	27
617	1.08	0.27	22.413	5.269	30.000	11.000	39
618	1.17	0.28	22.328	5.035	31.190	10.900	44
619	1.74	0.28	22.602	4.974	30.800	10.300	39
620	1.00	0.29	23.404	5.423	31.300	10.100	34
621	1.09	0.29	22.895	4.779	30.600	11.000	33
622	0.58	0.29	22.881	4.836	30.700	10.500	35
623	0.84	0.28	3.393	2.185	10.200	0.300	32
624	0.64	0.26	6.139	4.826	17.900	0.360	31
625	0.89	0.27	8.019	4.945	23.100	1.000	29
630	0.45	0.29	22.993	6.234	30.600	10.000	23
701	10.17	0.30	25.961	5.108	32.300	15.200	36
703	15.78	0.50	26.706	4.860	33.800	14.320	85
704	19.55	0.42	26.153	5.088	35.420	13.400	154
706	25.94	0.43	26.614	5.193	34.500	13.500	157
708	32.13	0.47	26.645	5.403	35.600	12.500	153
711	33.18	0.30	26.500	5.079	35.100	13.400	22

(Table A4, cont.)

713	27.31	0.30	26.548	5.264	34.600	13.900	23
715	21.81	0.30	26.132	4.892	34.400	13.800	25
717	15.41	0.30	26.276	4.843	34.200	13.000	25
719	9.69	0.30	25.888	4.949	32.400	10.200	25
857	10.55	0.65	21.380	5.479	28.790	11.890	25

TABLE A5

SALINITY STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

MID-DEPTH SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
52	32.98	16.42	33.963	1.844	39.000	28.000	148
53	32.98	16.45	34.169	1.956	39.200	26.300	156
54	26.93	13.55	33.187	2.296	39.500	23.500	149
55	33.90	16.82	34.229	1.975	38.600	24.100	148
481	31.13	15.49	34.999	2.356	43.400	30.500	48
482	31.49	15.70	34.816	2.581	43.200	25.800	48
484	30.85	15.41	34.993	2.151	44.000	31.500	43
500	10.67	5.18	28.864	2.740	33.100	21.500	25
501	10.67	5.18	28.220	4.001	32.200	12.400	25
502	10.62	5.19	27.648	4.633	32.200	13.000	27
505	10.67	5.18	29.784	2.567	34.600	24.200	25
506	10.67	5.18	29.820	2.550	35.200	24.600	25
507	10.67	5.18	28.735	3.412	32.400	19.200	26
535	10.40	5.16	27.652	4.631	32.400	13.600	21
703	15.76	7.78	30.155	2.991	34.980	21.990	81
704	19.50	9.74	31.597	2.629	35.900	20.500	152
706	25.87	12.99	33.110	2.182	36.400	23.000	148
708	32.11	16.05	33.955	1.955	36.600	27.400	150
713	27.30	13.57	32.967	2.386	35.000	23.900	21
715	21.81	10.96	31.724	2.954	35.100	21.500	25
717	15.41	7.96	30.528	3.401	34.200	17.800	25

TABLE A6

SALINITY STATISTICS FOR MONTHLY PHYSICAL HYDROGRAPHY SAMPLES:

BOTTOM SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
4	12.26	12.26	30.523	3.660	37.900	24.600	22
5	4.11	4.11	22.597	6.046	36.000	9.100	201
18	3.30	3.29	1.270	1.838	9.400	0.100	156
21	7.87	7.87	29.749	3.652	37.600	12.800	187
22	10.51	10.51	31.190	3.615	37.800	11.200	181
35	10.49	10.50	31.361	2.992	37.900	19.000	183
36	10.86	10.86	31.840	2.961	39.900	21.700	175
37	3.19	3.05	24.938	4.409	32.850	2.040	169
38	1.84	1.83	3.084	2.472	12.500	0.100	175
52	32.98	32.97	35.740	1.249	39.600	27.800	148
53	32.98	32.98	35.797	1.039	39.600	32.100	154
54	26.93	27.01	35.260	1.547	39.500	26.000	148
55	33.90	33.89	35.734	1.508	40.300	22.900	143
407	1.37	1.39	17.779	4.594	26.800	5.700	61
435	10.30	10.51	31.286	3.152	36.300	18.300	58
461	1.08	1.04	2.822	2.096	9.800	0.100	50
462	0.93	0.93	17.586	4.836	25.600	1.800	63
463	1.67	1.58	3.105	3.812	26.000	0.100	56
464	2.10	2.18	2.921	2.375	10.100	0.100	53
473	9.62	9.58	31.514	4.119	40.500	16.700	61
474	9.75	9.63	31.639	3.533	40.600	18.300	60
475	9.84	9.79	31.737	2.969	40.000	23.550	61
481	33.44	33.58	36.063	1.712	43.100	32.190	56
482	33.80	33.81	35.894	1.781	43.200	31.830	58
484	33.39	33.47	35.804	1.960	44.200	30.800	53
500	10.67	10.67	31.617	2.464	36.000	25.800	24
501	10.67	10.67	31.528	2.567	36.000	25.800	25
502	10.73	10.73	31.835	2.896	36.500	18.200	161
505	10.67	10.67	31.792	3.640	35.100	18.500	25
506	10.67	10.67	31.584	3.834	36.000	18.400	25
507	10.67	10.67	32.141	3.535	37.900	18.000	54
535	11.14	10.40	31.089	3.676	43.390	17.900	125
602	1.13	1.20	2.392	1.686	5.200	0.300	23
607	1.67	1.59	2.100	1.569	5.500	0.300	25
608	1.22	1.19	2.312	1.682	5.700	0.200	24
609	0.86	0.85	2.063	1.586	5.300	0.200	22

(Table A6, cont.)

610	1.34	1.34	2.498	1.983	6.400	0.200	23
611	1.51	1.51	3.430	3.423	10.700	0.210	26
615	0.49	0.49	17.464	6.092	30.700	0.070	21
617	1.02	0.99	20.580	4.960	28.780	12.100	23
618	1.35	1.33	21.153	4.891	31.570	11.000	30
619	1.42	1.42	21.941	5.402	32.280	13.560	24
620	0.82	0.83	22.861	4.998	31.990	13.380	31
621	0.61	0.66	21.587	5.032	32.530	13.510	24
701	10.17	7.68	31.878	6.231	57.700	22.000	36
703	15.79	16.05	33.917	1.562	37.000	30.000	84
704	19.55	19.65	34.531	1.463	37.700	30.700	154
706	25.93	25.69	35.205	1.205	38.900	29.330	156
708	32.13	32.16	35.565	1.148	38.200	29.600	154
713	27.31	27.24	35.082	0.798	36.200	33.200	22
715	22.65	22.65	34.557	0.758	36.100	33.100	23
717	16.46	16.44	33.733	1.022	35.200	31.500	21
719	9.69	9.33	31.344	2.332	34.500	24.900	25
857	10.55	10.19	30.553	2.008	34.150	27.680	25

TABLE A7

SALINITY STATISTICS FOR MONTHLY WATER CHEMISTRY SAMPLES:

SURFACE SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
1	1.89	0.30	12.030	6.330	26.000	0.700	37
2	2.04	0.30	19.459	6.745	31.200	4.300	37
3	2.58	0.30	20.358	7.487	33.100	6.000	36
4	11.73	0.30	22.619	5.790	34.900	10.900	26
5	4.16	0.29	22.359	5.727	35.500	9.200	105
6	2.20	0.30	22.436	4.430	29.900	14.100	22
7	1.63	0.29	17.866	4.451	27.700	7.900	104
8	1.73	0.31	18.516	4.553	27.900	11.090	30
9	1.95	0.30	18.250	5.257	27.000	9.600	22
10	1.98	0.34	18.205	4.783	25.400	10.300	28
11	2.54	0.30	9.600	5.063	25.100	2.500	21
12	1.66	0.28	9.434	4.741	21.400	1.400	69
13	1.50	0.31	8.770	4.548	22.700	0.600	91
14	1.93	0.28	3.608	3.923	16.800	0.100	102
15	1.79	0.31	3.522	2.976	14.100	0.360	104
16	2.27	0.30	2.125	2.654	12.000	0.200	40
17	1.59	0.30	2.257	1.952	7.600	0.100	21
18	3.23	0.28	0.904	1.323	8.300	0.080	96
19	1.95	0.30	1.967	1.600	5.800	0.200	21
21	7.88	0.41	25.546	5.391	36.500	9.960	97
22	10.53	0.42	26.064	5.320	35.200	11.400	97
34	1.76	0.29	24.189	4.486	33.300	12.600	97
35	10.52	0.41	25.944	5.137	35.200	11.940	92
36	10.88	0.49	25.946	5.221	34.600	11.500	90
37	3.32	0.35	24.514	4.367	33.900	12.800	93
38	1.88	0.31	2.798	2.292	11.400	0.500	93
39	1.70	0.29	2.731	2.098	11.000	0.470	57
52	32.93	0.43	25.942	5.212	36.800	8.300	74
53	33.16	0.44	26.786	5.642	35.900	11.200	80
54	27.03	0.38	26.372	4.803	34.330	9.000	76
55	34.01	0.44	26.789	5.419	35.500	8.600	76
435	9.78	0.44	25.349	6.234	34.400	11.800	31
473	9.32	0.35	24.541	5.493	34.900	15.200	32
474	9.39	0.37	24.623	5.363	36.200	15.700	31
475	9.67	0.41	24.537	6.210	35.200	12.200	32
481	32.34	0.44	25.108	5.928	35.410	9.300	29

(Table A7, cont.)

482	33.13	0.36	24.899	6.244	35.200	10.900	30
484	32.63	0.45	26.491	5.266	35.600	15.700	29
502	10.68	0.40	25.445	5.690	33.900	8.600	79
507	10.67	0.30	26.111	5.558	32.500	9.300	27
535	11.88	0.42	24.745	5.593	32.000	8.300	64
704	19.48	0.46	26.776	5.027	34.300	12.500	62
706	26.05	0.45	26.587	5.440	36.400	13.400	70
708	32.41	0.51	27.266	5.629	35.700	13.400	66

TABLE A8

SALINITY STATISTICS FOR MONTHLY WATER CHEMISTRY SAMPLES:

MID-DEPTH SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
52	32.89	16.49	33.141	3.520	37.100	15.000	75
53	33.17	16.57	33.837	2.205	37.300	27.400	78
54	27.03	13.61	32.790	3.331	37.100	16.600	76
55	33.97	16.98	34.468	1.846	37.750	30.100	72
704	19.48	9.79	31.836	2.758	36.130	22.700	62
706	26.05	13.19	33.368	2.162	36.800	26.700	66
708	32.38	16.17	33.996	1.940	37.300	29.600	64

TABLE A9

SALINITY STATISTICS FOR MONTHLY WATER CHEMISTRY SAMPLES:

BOTTOM SAMPLES 1/1/78-12/31/95

General descriptive statistics for selected stations (Sta). Mean measured seafloor depth at the station ($z_{seafloor}$) is listed in meters, as is mean sampling depth (z_{sample}). Mean (μ), standard deviation from the mean (σ), maximum (Max), and minimum (Min) are listed in ppt. The number of measurements used to compute these statistics is n.

Sta	$z_{seafloor}$	z_{sample}	μ	σ	Max	Min	n
4	12.01	12.01	31.679	2.837	37.600	26.000	24
5	4.21	4.22	23.292	5.808	35.500	9.600	97
18	3.25	3.25	1.188	1.785	8.600	0.080	89
21	7.87	7.79	29.490	3.465	35.900	19.300	94
22	10.61	10.61	30.644	3.657	36.200	15.000	94
35	10.52	10.50	30.781	3.257	35.900	21.400	93
36	10.88	10.88	31.112	3.321	35.770	19.100	90
37	3.33	3.30	24.932	4.204	33.900	12.800	92
38	1.88	1.87	2.866	2.408	12.300	0.590	91
52	32.89	32.95	35.667	1.296	38.660	29.100	74
53	33.17	33.18	35.614	1.311	38.300	32.300	77
54	27.02	29.04	34.978	1.773	37.750	25.900	76
55	34.01	34.01	35.802	1.096	37.800	32.500	76
407	1.37	1.40	19.611	3.652	28.500	13.010	26
435	9.99	10.88	30.489	4.219	37.000	17.900	30
461	1.10	1.03	2.287	1.582	6.400	0.500	28
462	0.95	0.95	17.962	3.775	24.600	8.600	31
463	1.50	1.51	2.230	1.660	6.200	0.500	29
464	2.16	2.14	2.458	1.527	6.400	0.660	31
473	9.61	9.56	31.698	3.247	38.200	23.400	29
474	9.73	9.66	30.503	6.399	40.800	1.900	28
475	9.94	9.90	31.220	2.919	36.800	23.000	29
481	33.26	33.48	35.304	1.365	37.100	30.700	27
482	34.04	33.96	35.481	1.980	42.200	30.700	28
484	33.61	33.51	35.399	2.076	37.030	27.900	26
502	10.71	10.72	31.684	2.683	38.400	24.400	80
507	10.67	10.67	31.327	3.345	35.200	19.800	26
535	11.88	10.37	30.535	3.513	35.700	18.600	64
704	19.49	19.63	34.616	1.420	36.800	30.400	61
706	26.05	25.90	34.934	1.891	37.500	27.500	68
708	32.39	32.41	35.585	1.388	37.900	30.000	65

TABLE A10

TEMPERATURE STATISTICS AT FIXED STATIONS

General descriptive statistics for measurements taken at fixed stations. Mean (μ), standard deviation from the mean (σ), maximum, and minimum are listed in units of °C.

Station	Timespan*	μ	σ.	Maximum	Minimum
306	4/20/81-6/17/81	24.5052	1.8118	28.8000	21.3000
315	2/1/78-12/31/95	22.5689	6.5807	36.2200	2.8000
317	5/10/78-11/4/95	22.4801	6.1777	32.9600	3.7700
318	6/18/81-1/23/86	24.7698	4.0466	35.0000	14.6000
318	5/24/78-6/18/80	24.0938	2.4440	28.9000	20.6500
319	4/28/81-1/23/86	24.9349	5.1881	34.2000	9.4200
319	5/25/78-6/13/80	21.6426	5.0407	31.9000	11.0500
320	5/11/78-5/28/80	21.7561	2.5766	25.4500	15.9500
321	5/27/78-5/28/80	N/A	N/A	N/A	N/A
323	9/6/78-6/14/80	16.5064	4.1546	24.0500	5.9500
323	3/30/81-5/11/88	23.2963	6.4802	34.0000	3.5000
323	5/11/88-2/6/92	22.9520	6.3238	33.8700	4.1730
324	12/15/78-7/29/79	N/A	N/A	N/A	N/A
325	2/20/90-12/31/95	22.9224	6.8861	38.1000	2.3700
326	5/22/81-9/3/87	21.6961	7.1270	38.2000	0.5000
326	7/28/88-12/31/95	22.0407	6.4844	36.8600	2.4800
335	3/11/82-12/2/85	24.5725	3.2791	33.4000	14.4600

* Statistics for individual stations are found separately for time periods when different instruments were used; see figure 1 for instruments, and figure 2 for location of stations.

TABLE A11

SALINITY STATISTICS AT FIXED STATIONS

General descriptive statistics for measurements taken at fixed stations. Mean (μ), standard deviation from the mean (σ), maximum, and minimum are listed in units of ppt.

Station	Timespan*	μ	σ.	Maximum	Minimum
306	4/20/81-6/17/81	30.5839	2.5828	35.2400	23.5600
315	2/1/78-12/31/95	19.2884	5.6141	36.1000	2.4990
317	5/10/78-11/4/95	13.0936	6.2869	31.6980	0.2000
318	5/24/78-6/18/80	27.9325	2.6336	33.9600	19.0900
318	6/18/81-1/23/86	27.3489	4.4835	37.5940	13.9700
319	5/25/78-6/13/80	21.2231	6.5830	34.5700	6.6200
319	4/28/81-1/23/86	27.2142	4.7469	41.9200	12.4940
320	5/11/78-5/28/80	1.7604	1.7466	7.8300	0.0600
321	5/27/78-5/28/80	3.3822	1.3102	7.5900	0.1200
323	9/6/78-6/14/80	18.8444	5.6484	34.1900	6.0400
323	3/30/81-5/11/88	20.2641	4.7773	33.2700	5.3640
323	5/11/88-2/6/92	20.2888	5.5293	34.6990	3.7990
324	12/15/78-7/29/79	0.1108	0.1290	0.9800	0.0600
325	2/20/90-12/31/95	2.9384	1.9419	9.3020	0.3000
326	5/22/81-9/3/87	4.8886	2.8049	15.3320	0.1900
326	7/28/88-12/31/95	2.1448	2.1250	10.2000	0.1000
335	3/11/82-12/2/85	28.4266	4.6802	41.4700	14.2620

* Statistics for individual stations are found separately for time periods when different instruments were used; see figure 1 for instruments, and figure 2 for location of stations.

TABLE A12

EAST VELOCITY STATISTICS AT FIXED STATIONS

General descriptive statistics for measurements taken at fixed stations. Mean (μ), standard deviation from the mean (σ), maximum, and minimum are listed in meters per second.

Station	Timespan*	μ	σ.	Maximum	Minimum
306	4/20/81-6/17/81	-0.0267	0.0844	0.2288	-0.2830
318	6/18/81-1/23/86	-0.0060	0.0968	0.3023	-0.3156
319	4/28/81-1/23/86	-0.0276	0.1305	0.3964	-0.4543
335	3/11/82-12/2/85	0.0163	0.1173	0.4001	-0.3645

TABLE A13

NORTH VELOCITY STATISTICS AT FIXED STATIONS

General descriptive statistics for measurements taken at fixed stations. Mean (μ), standard deviation from the mean (σ), maximum, and minimum are listed in meters per second.

Station	Timespan*	μ	σ.	Maximum	Minimum
306	4/20/81-6/17/81	-0.0134	0.0834	0.2465	-0.2747
318	6/18/81-1/23/86	-0.0128	0.0940	0.2888	-0.3210
319	4/28/81-1/23/86	-0.0291	0.0925	0.2861	-0.3468
335	3/11/82-12/2/85	0.0059	0.0910	0.2947	-0.2861

APPENDIX B

PHYSICAL HYDROGRAPHY PLOTS

OF MONTHLY TEMPERATURE AND SALINITY OBSERVATIONS

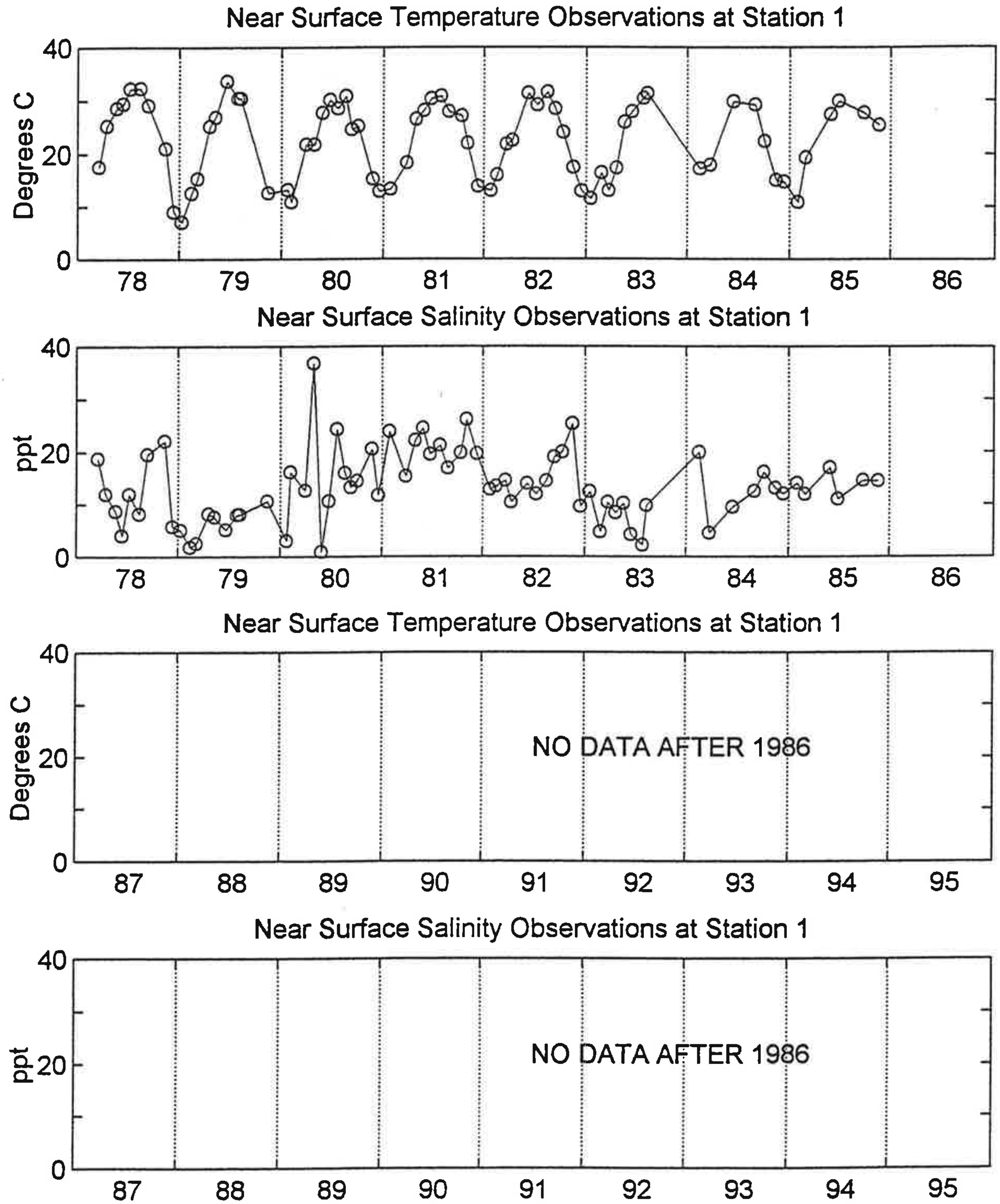

Figure B1. Station 1 monthly physical hydrography data: top temperatures and salinities.

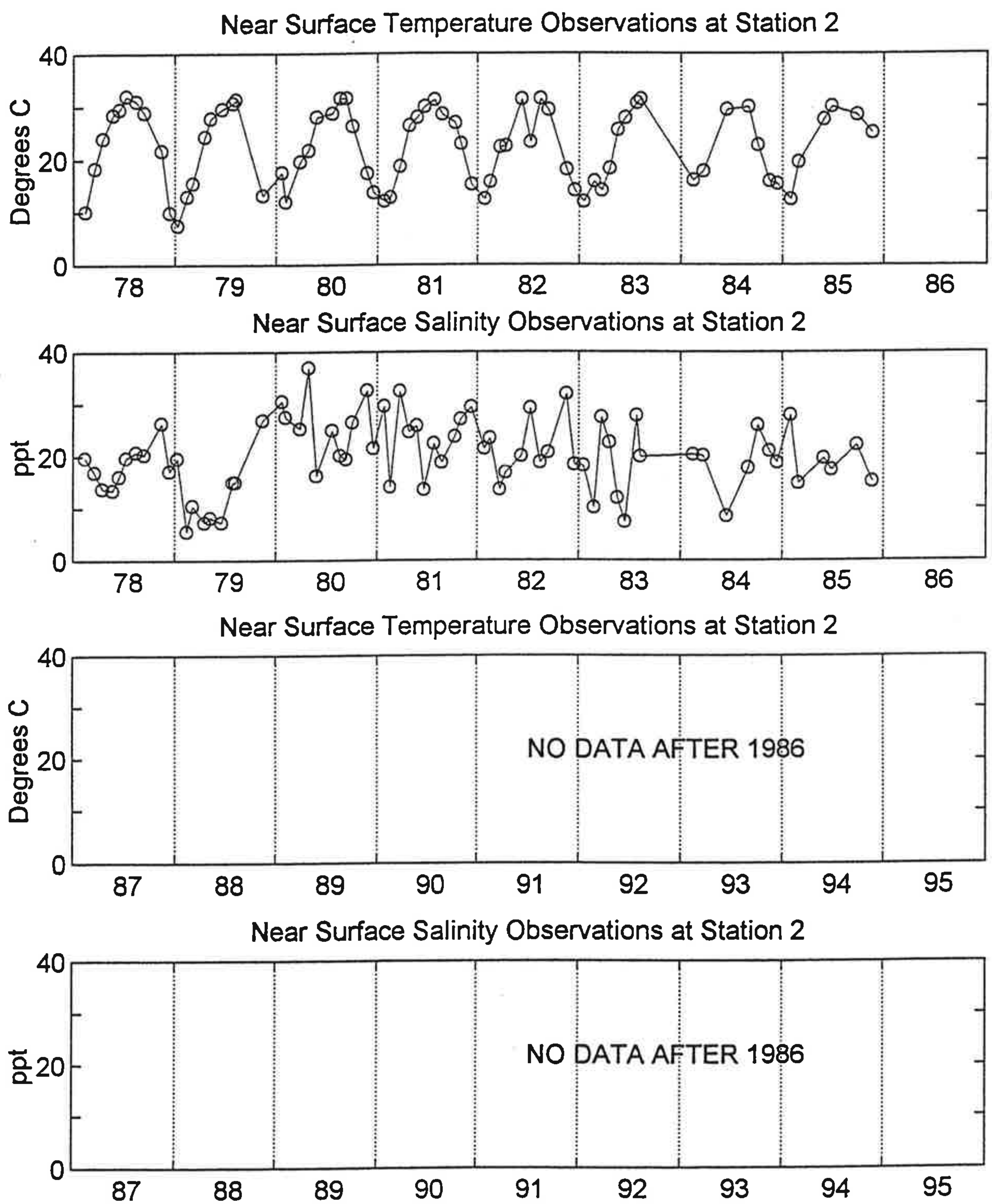

Figure B2. Station 2 monthly physical hydrography data: top temperatures and salinities.

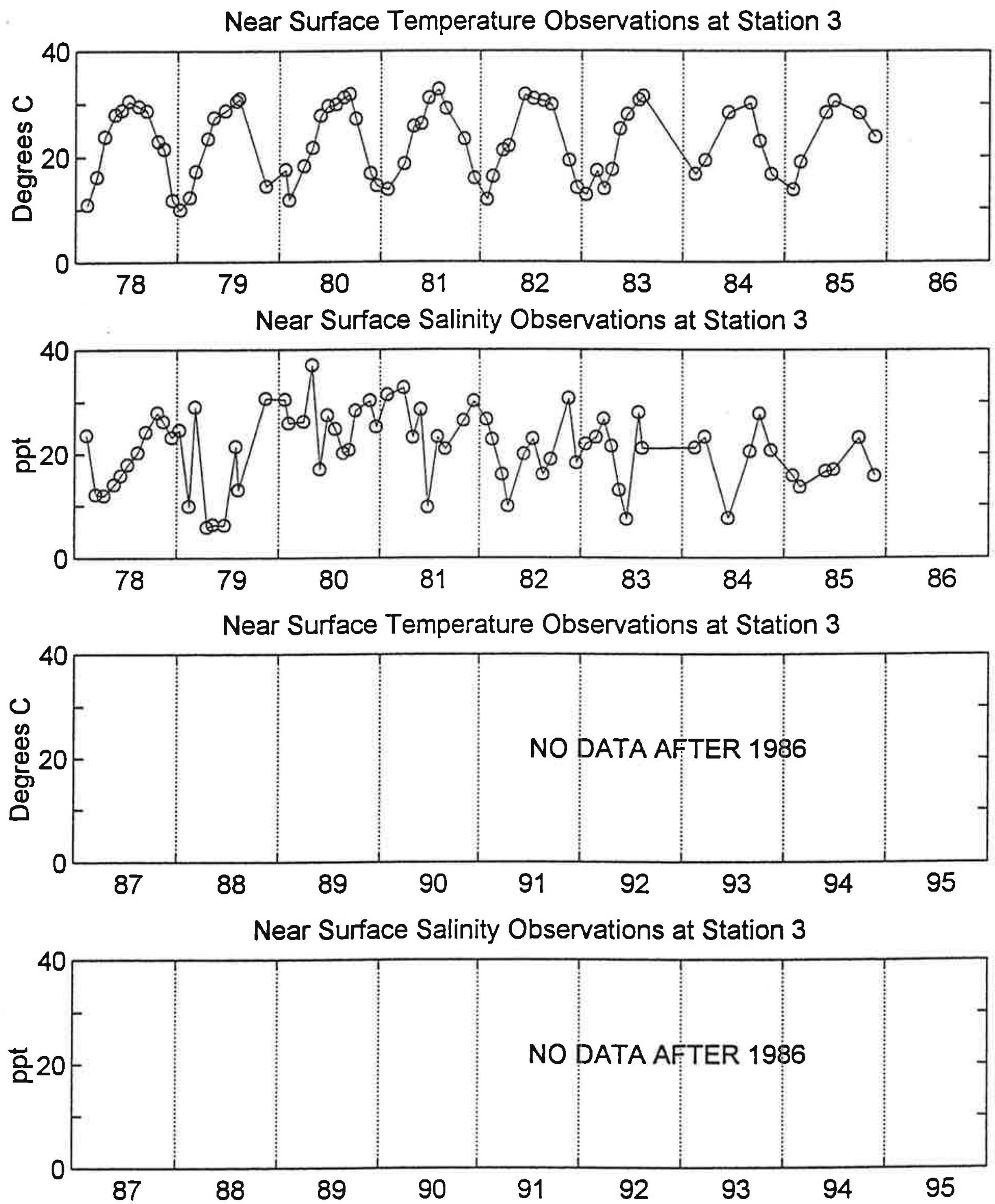

Figure B3. Station 3 monthly physical hydrography data: top temperatures and salinities.

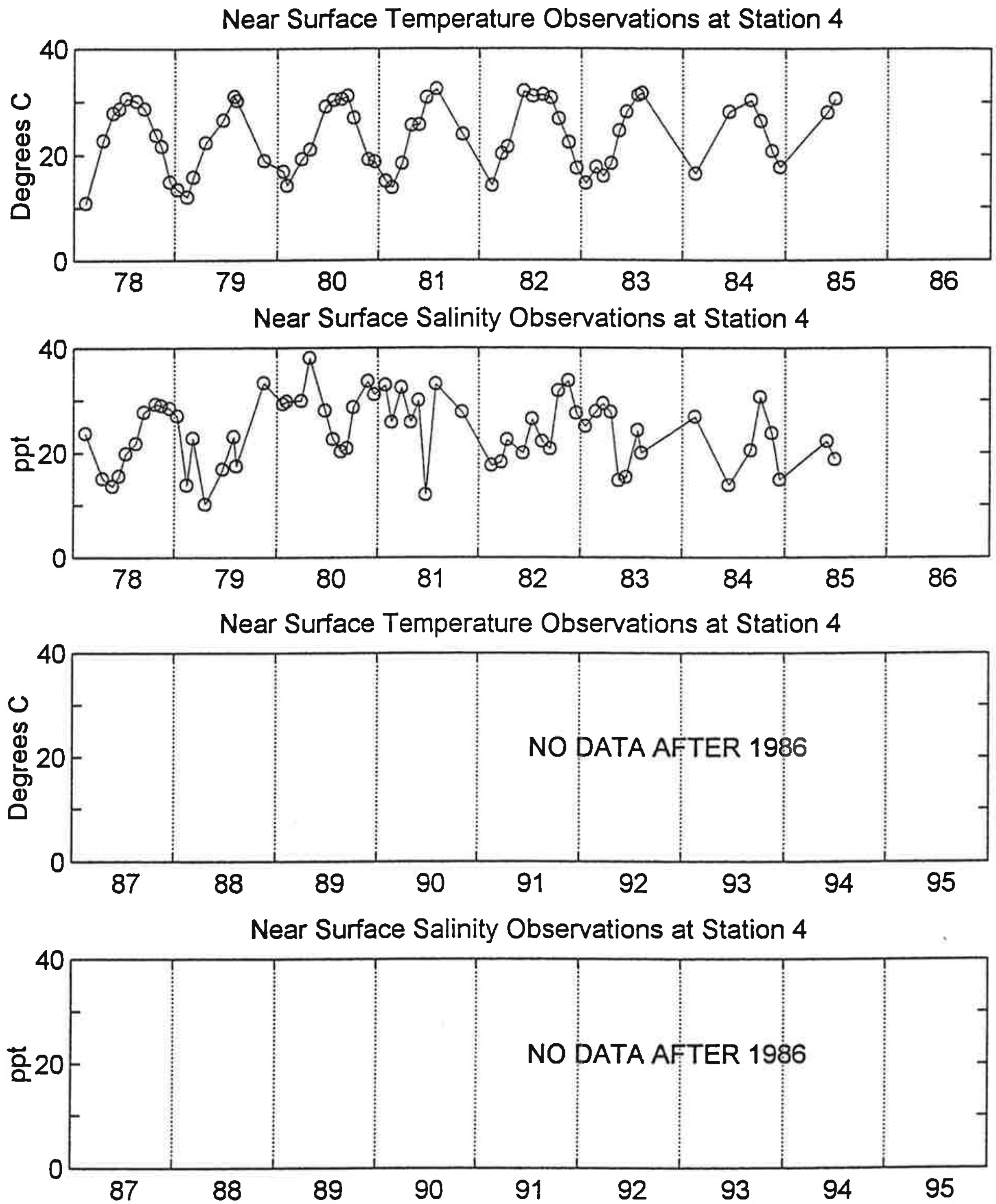

Figure B4. Station 4 monthly physical hydrography data: top temperatures and salinities.

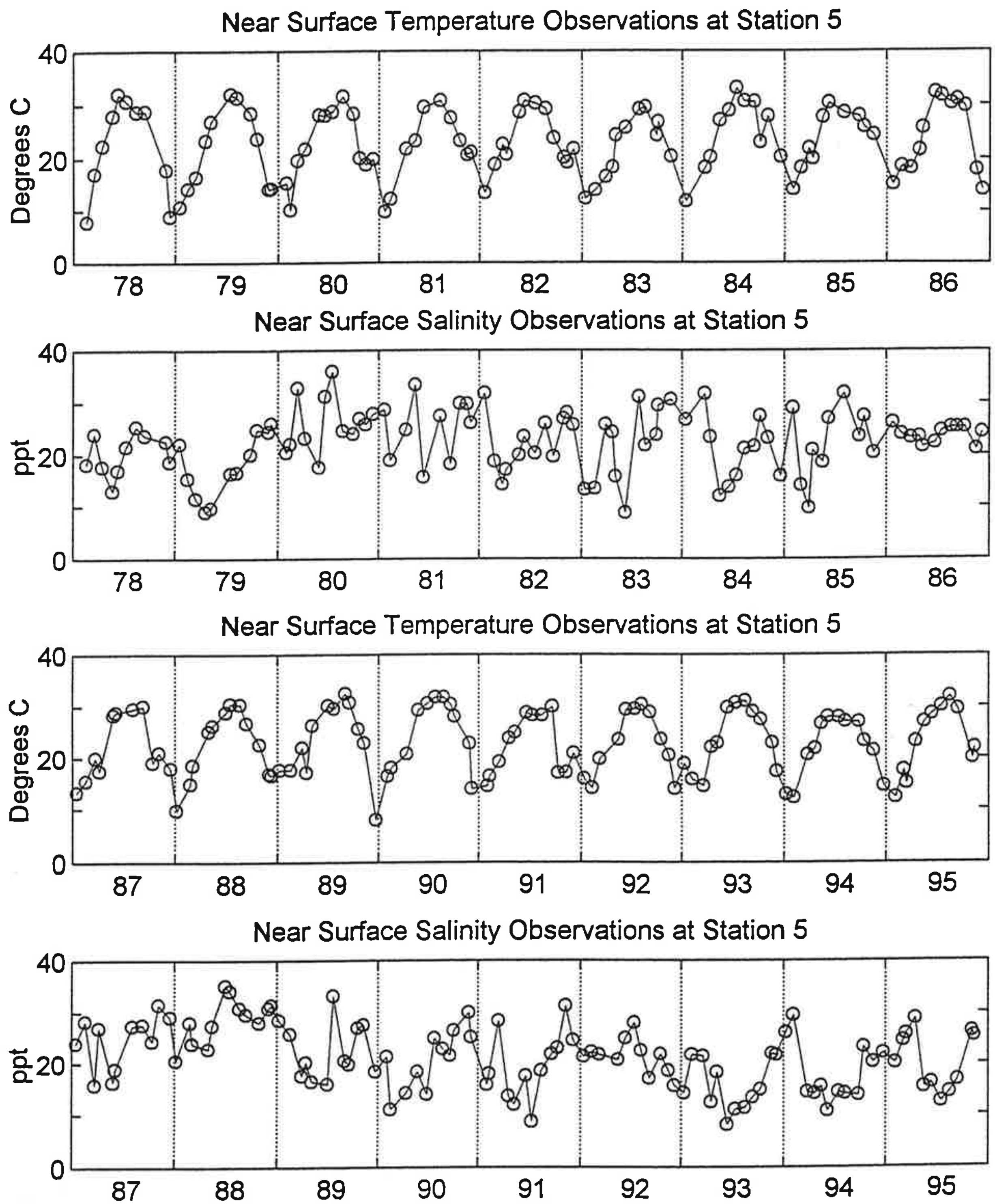

Figure B5. Station 5 monthly physical hydrography data: top temperatures and salinities.

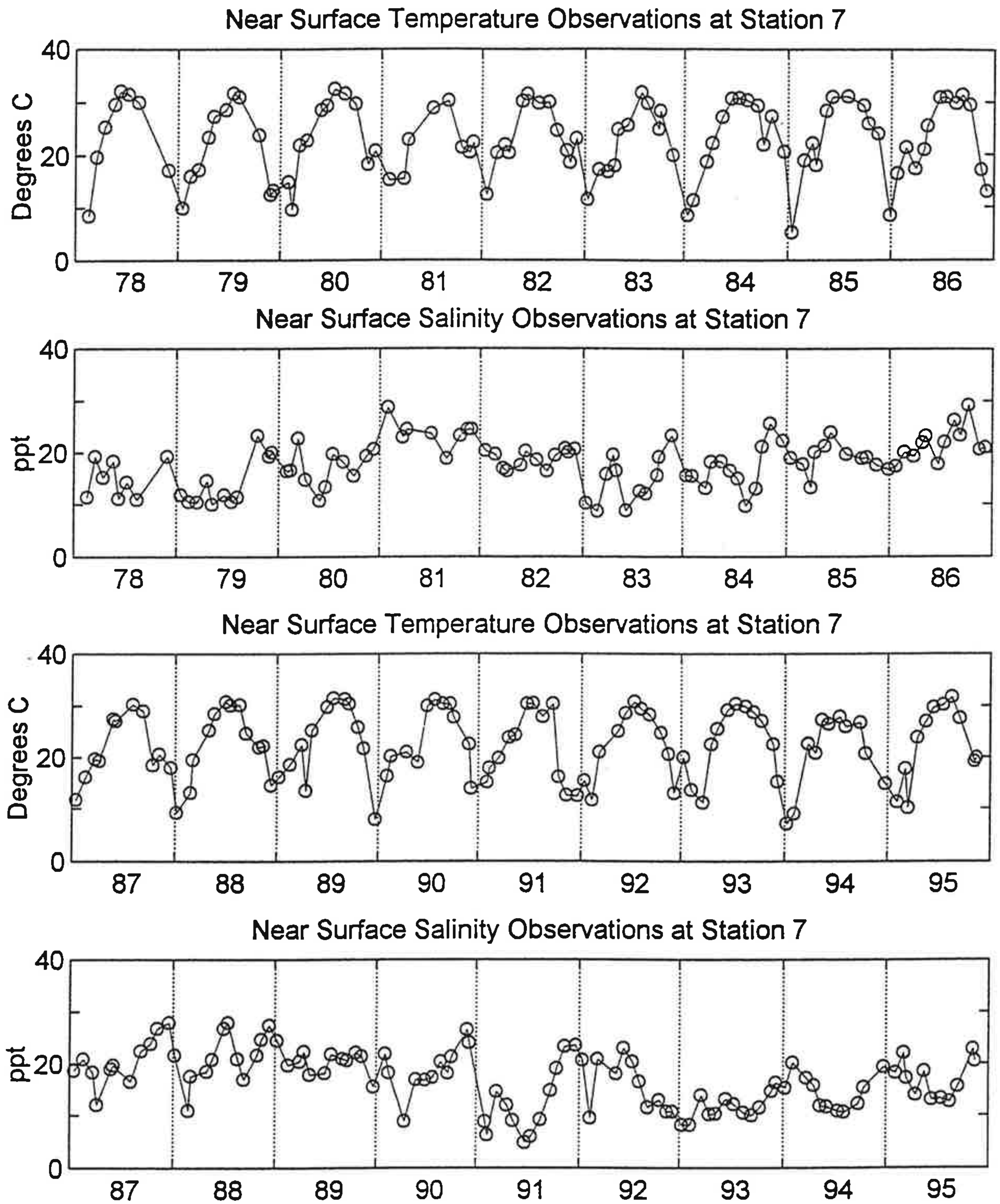

Figure B6. Station 7 monthly physical hydrography data: top temperatures and salinities.

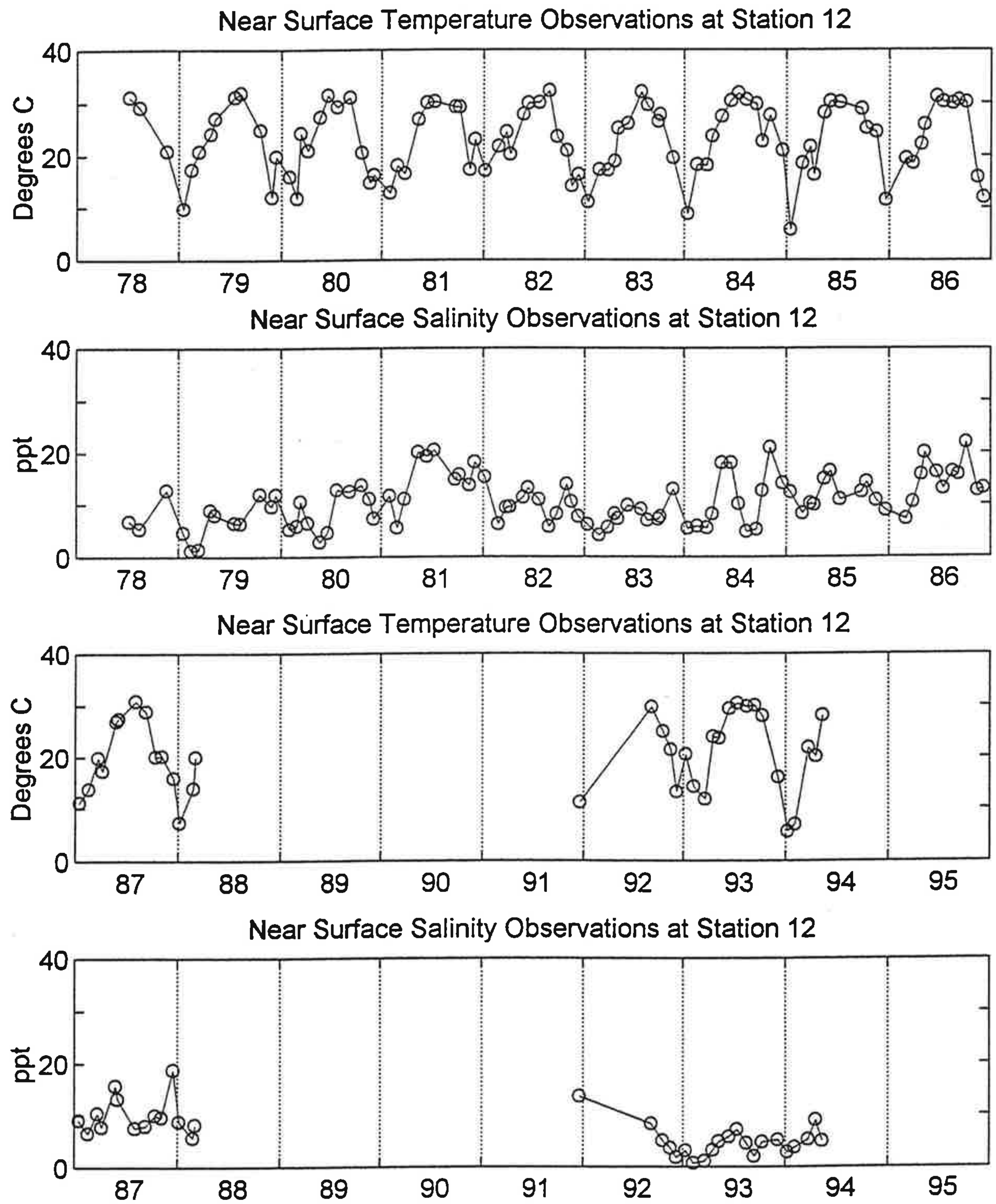

Figure B7. Station 12 monthly physical hydrography data: top temperatures and salinities.

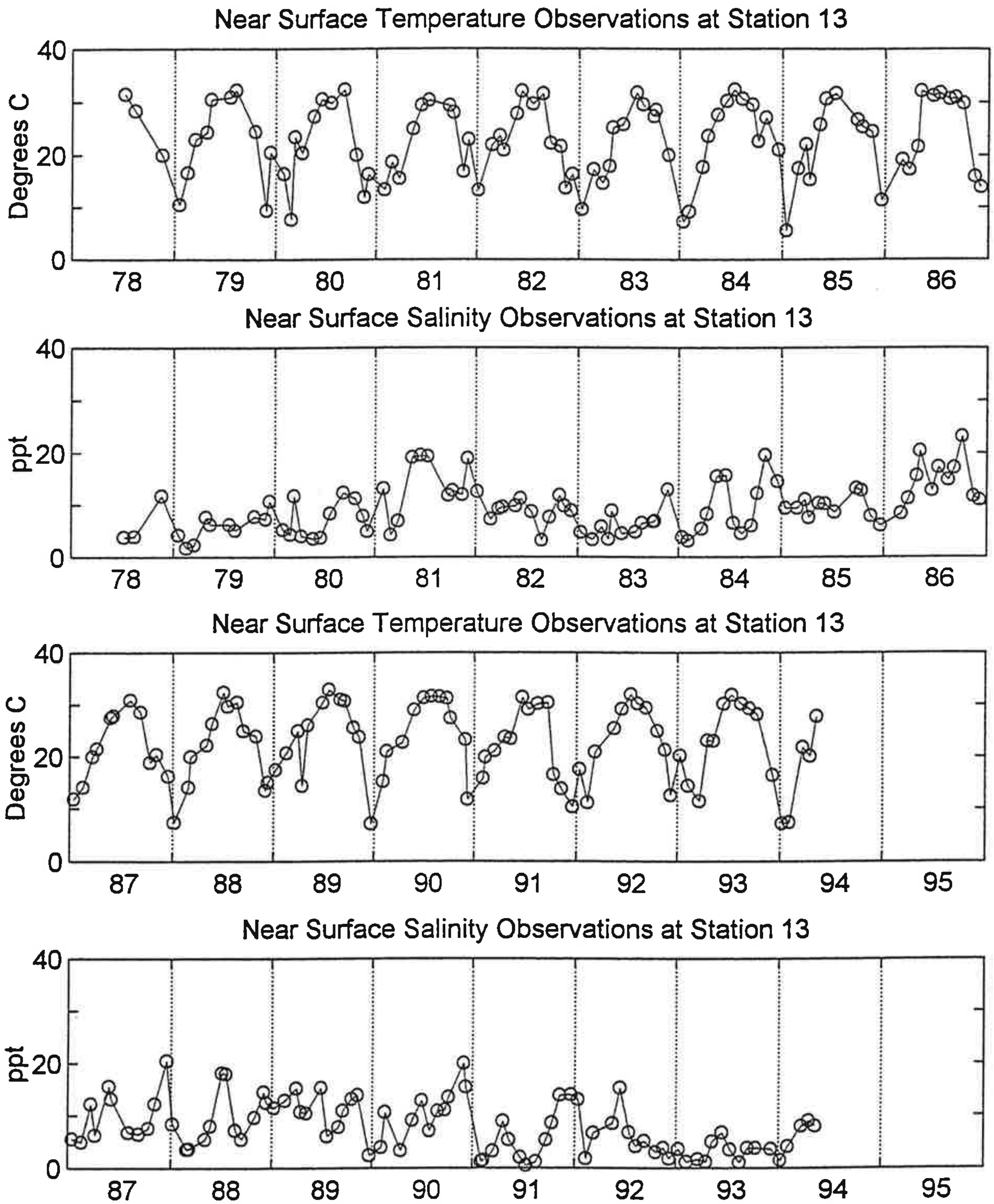

Figure B8. Station 13 monthly physical hydrography data: top temperatures and salinities.

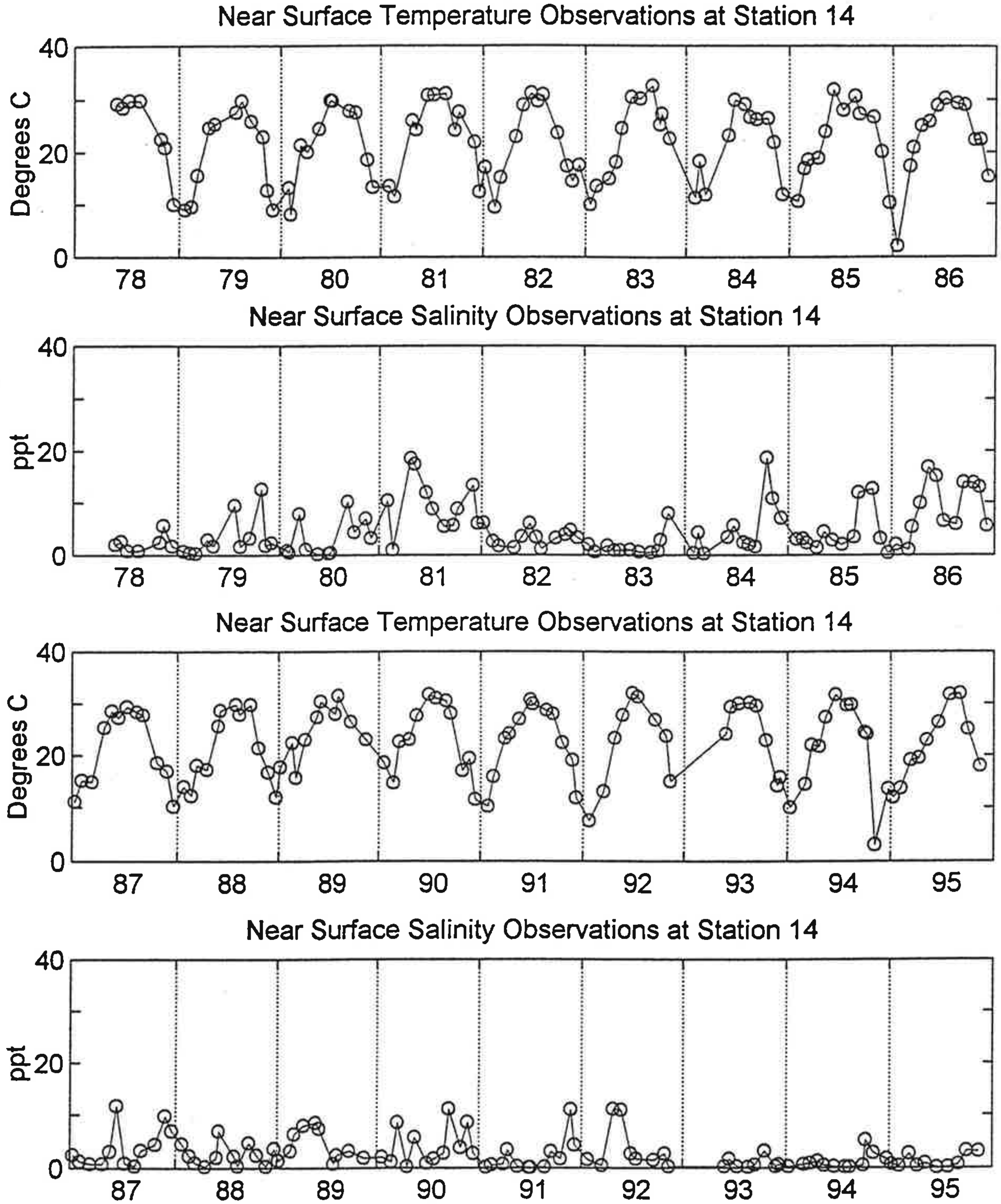

Figure B9. Station 14 monthly physical hydrography data: top temperatures and salinities.

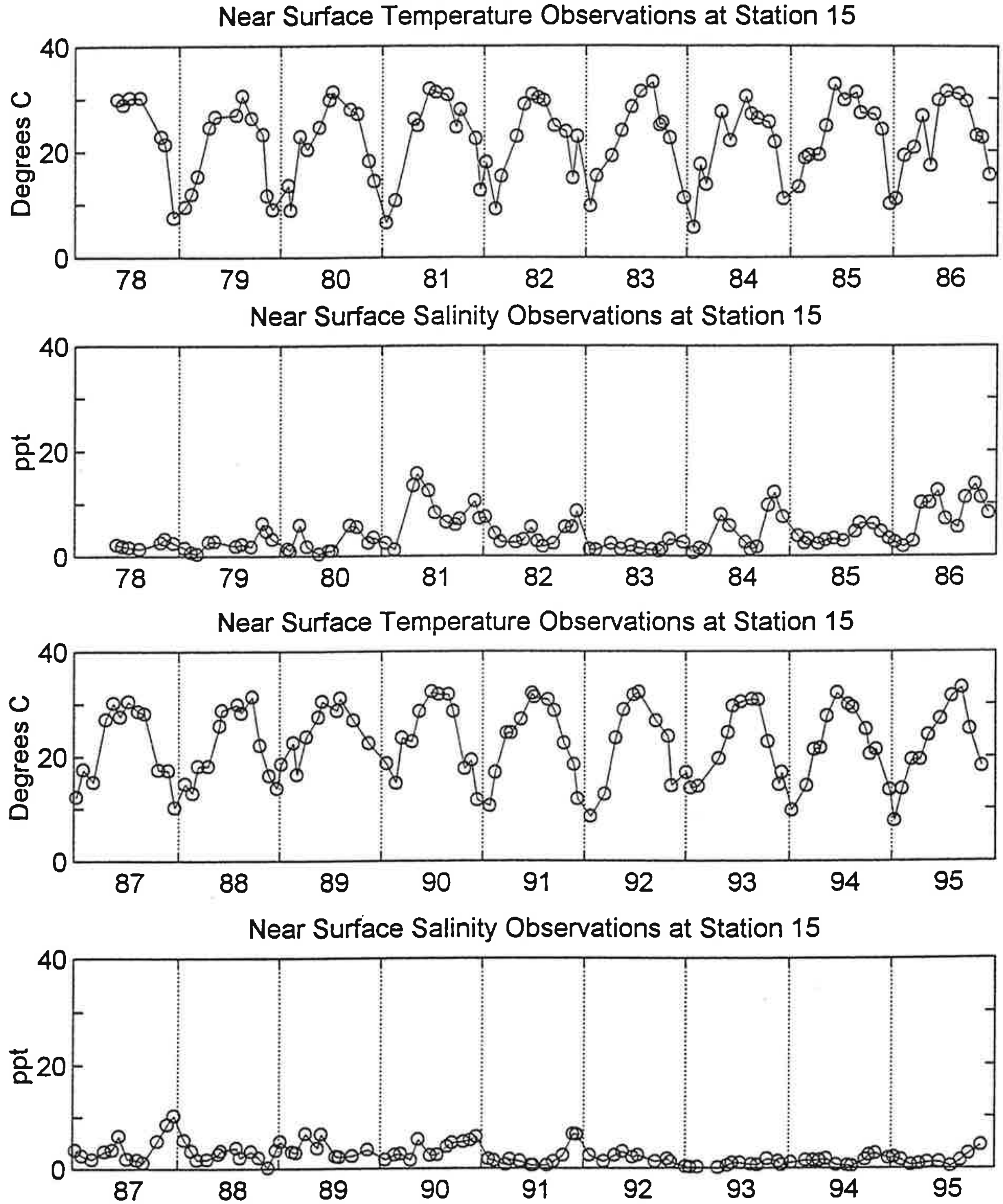

Figure B10. Station 15 monthly physical hydrography data: top temperatures and salinities.

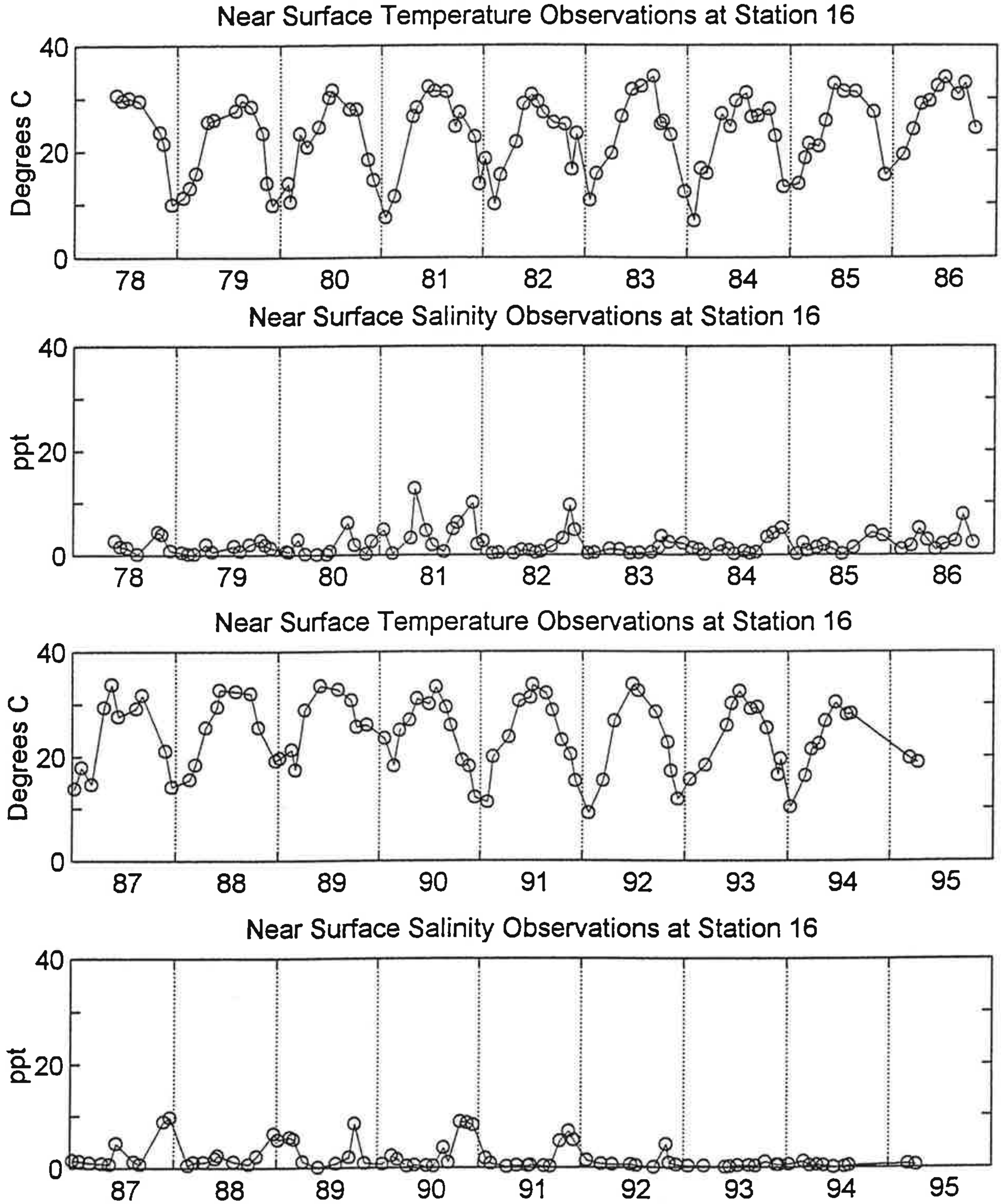

Figure B11. Station 16 monthly physical hydrography data: top temperatures and salinities.

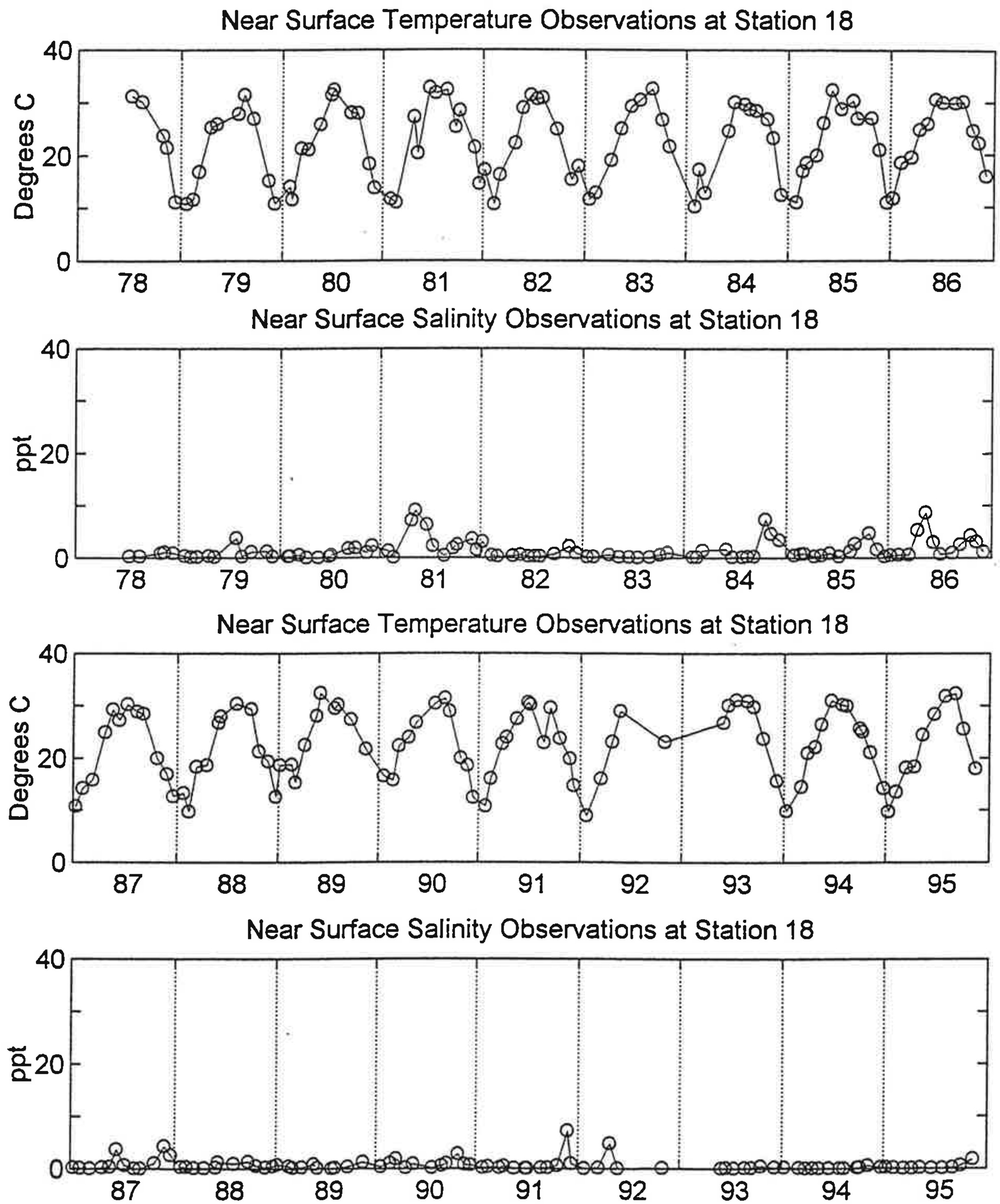

Figure B12. Station 18 monthly physical hydrography data: top temperatures and salinities.

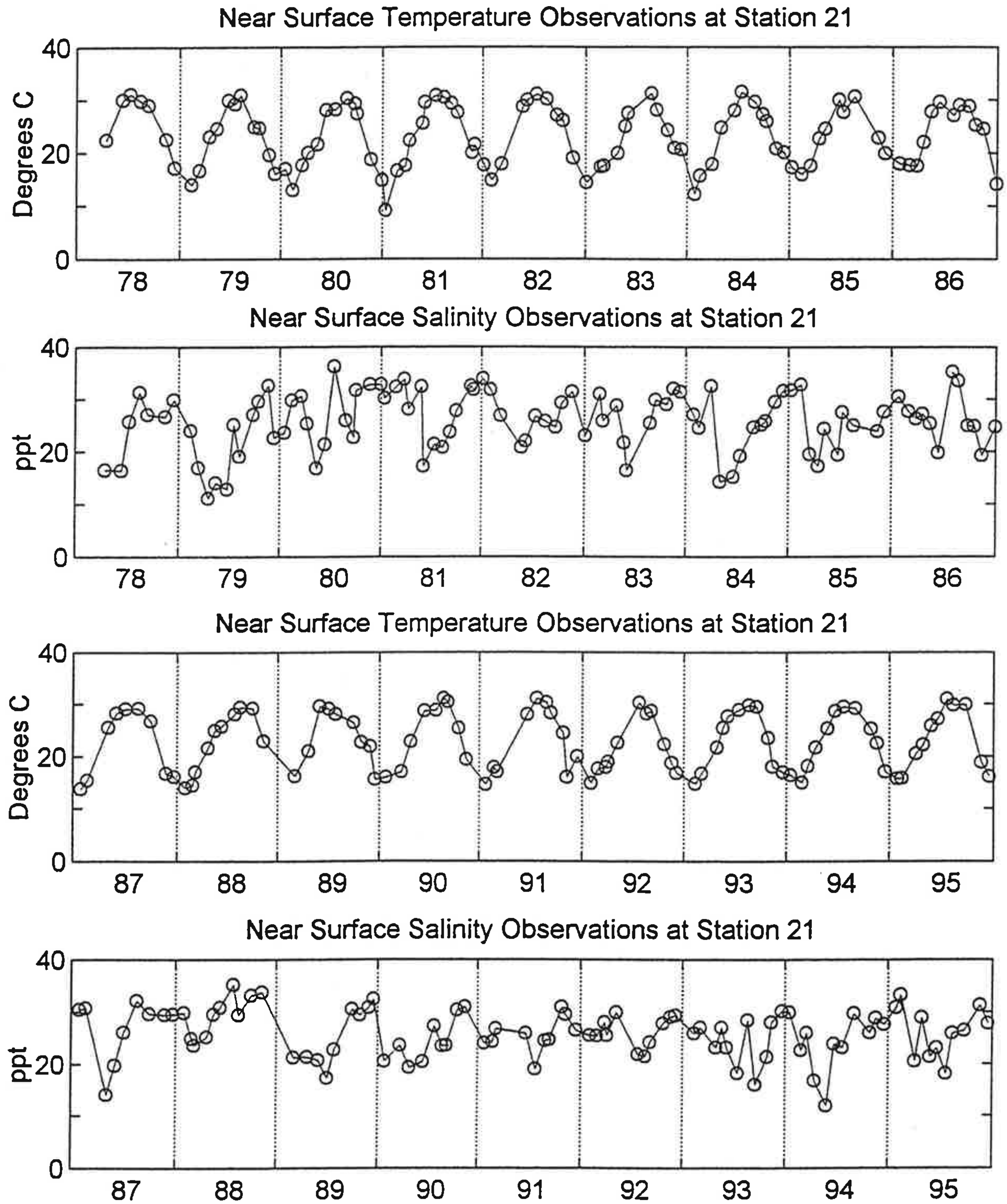

Figure B13. Station 21 monthly physical hydrography data: top temperatures and salinities.

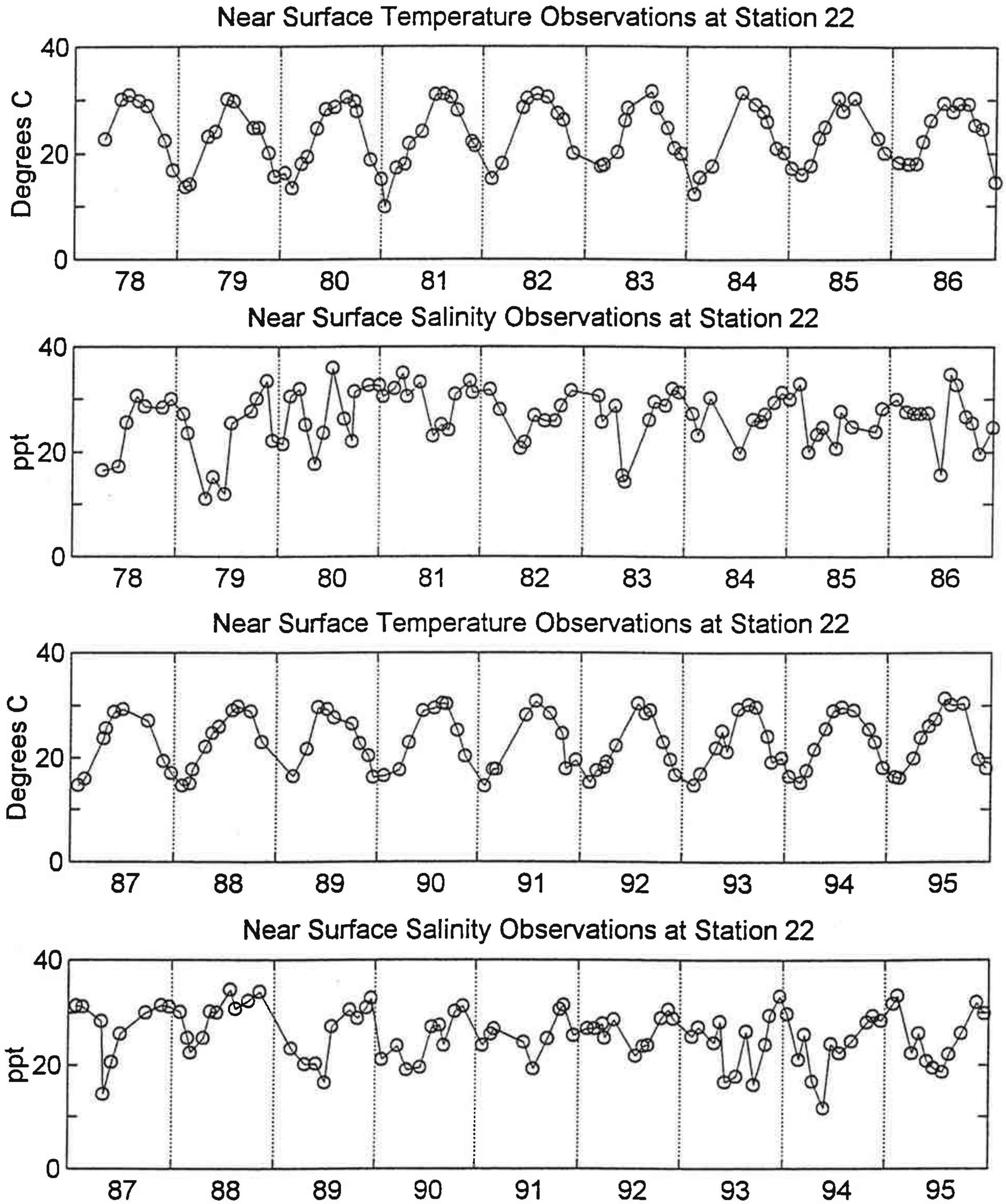

Figure B14. Station 22 monthly physical hydrography data: top temperatures and salinities.

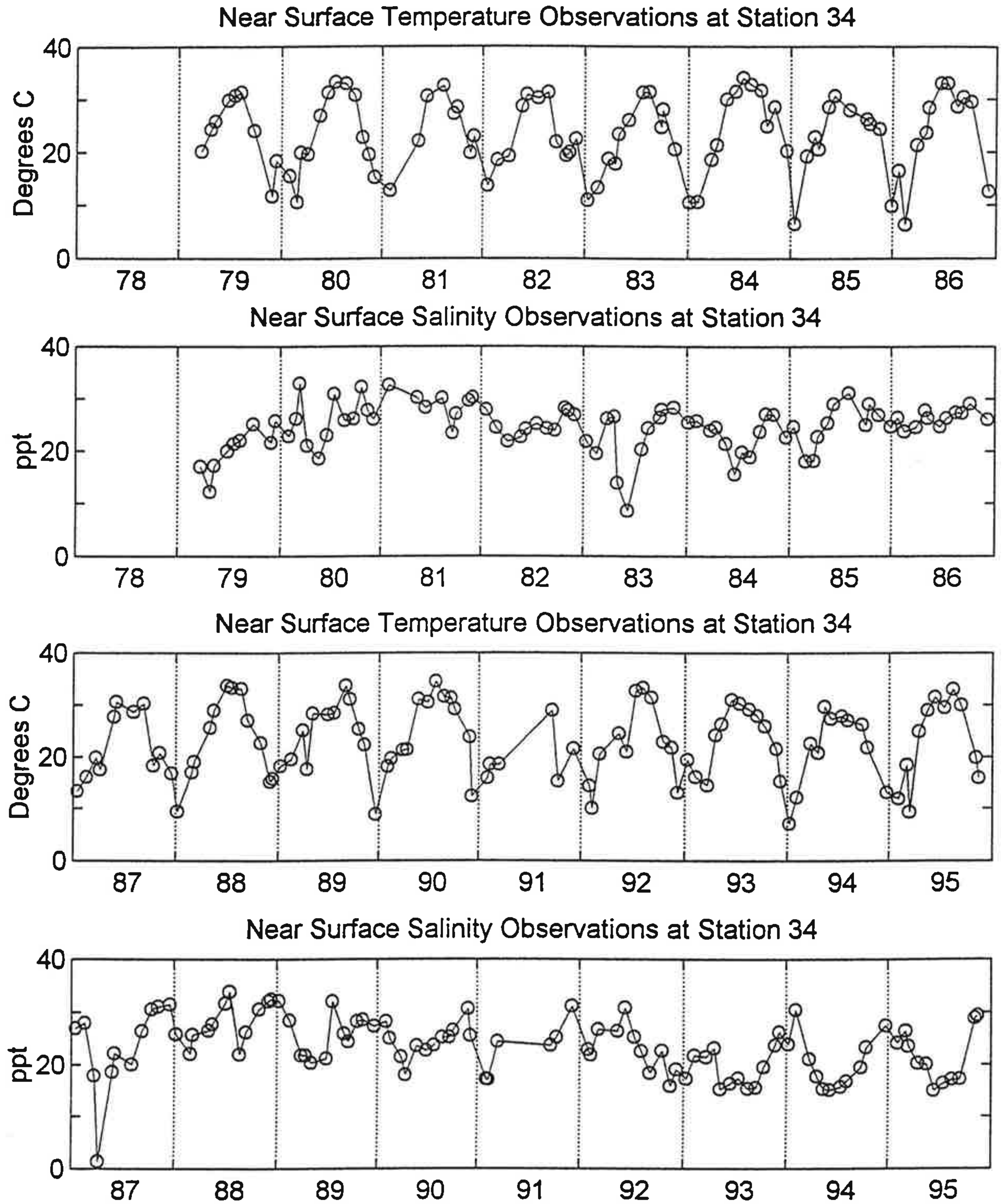

Figure B15. Station 34 monthly physical hydrography data: top temperatures and salinities.

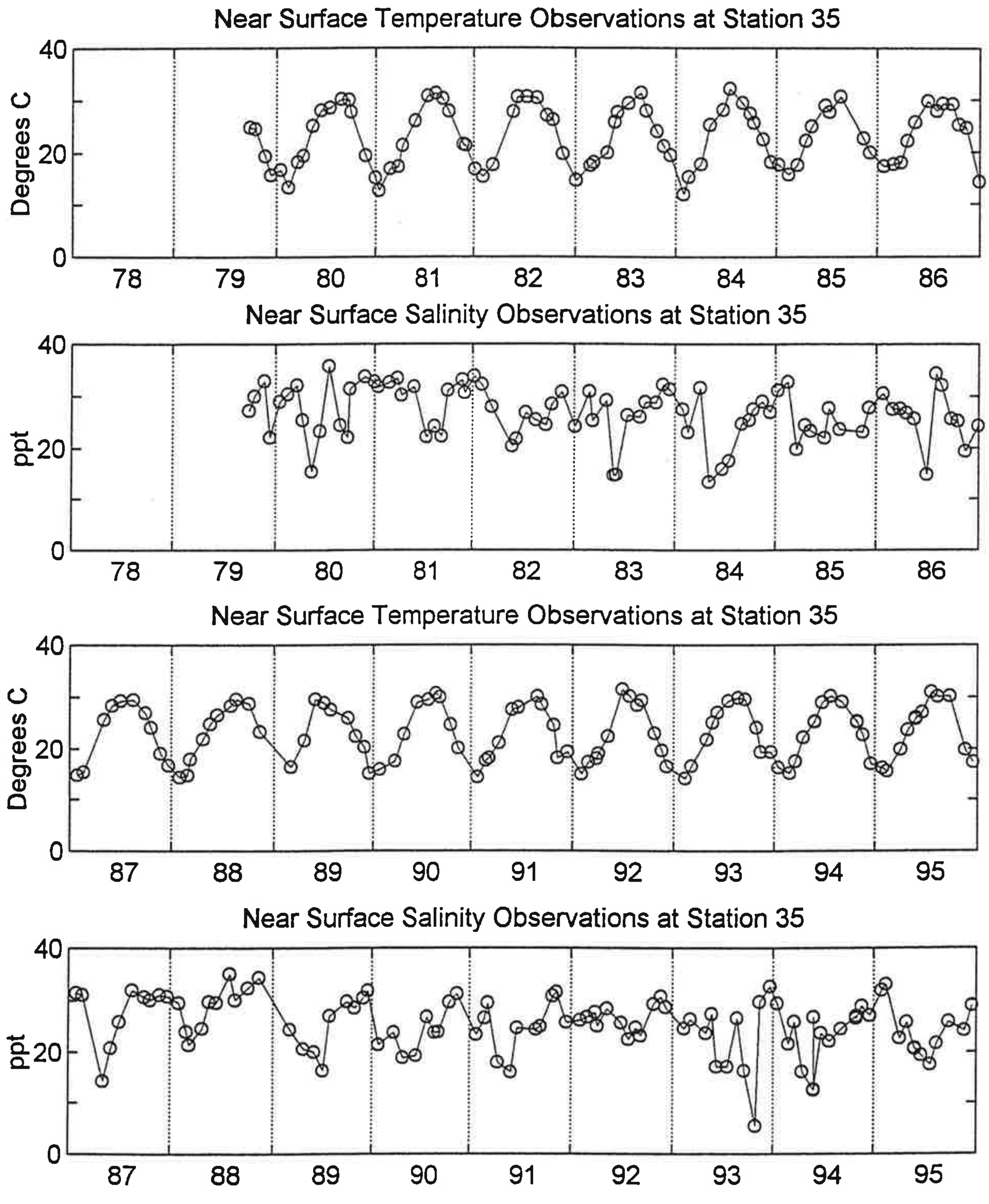

Figure B16. Station 35 monthly physical hydrography data: top temperatures and salinities.

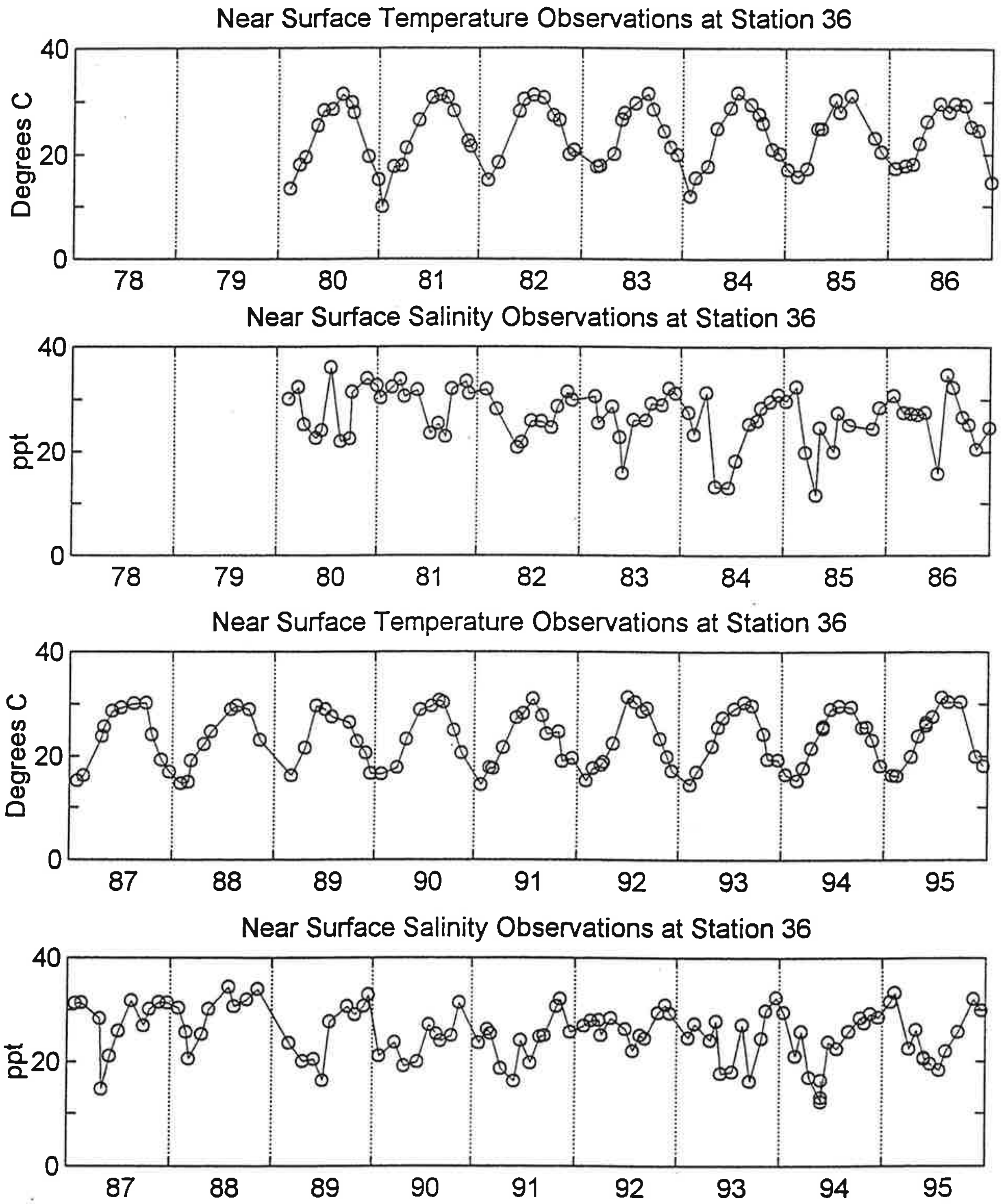

Figure B17. Station 36 monthly physical hydrography data: top temperatures and salinities.

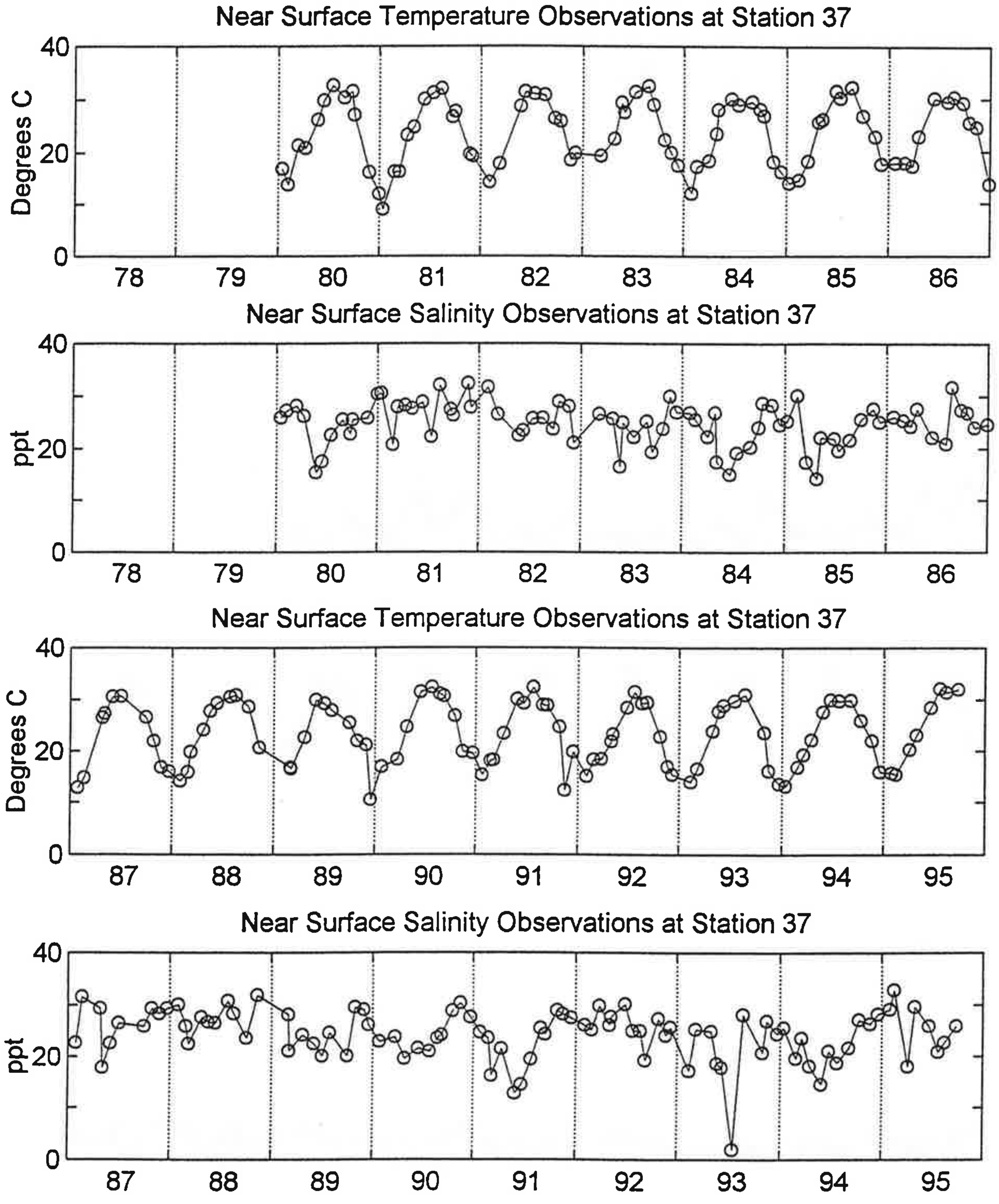

Figure B18. Station 37 monthly physical hydrography data: top temperatures and salinities.

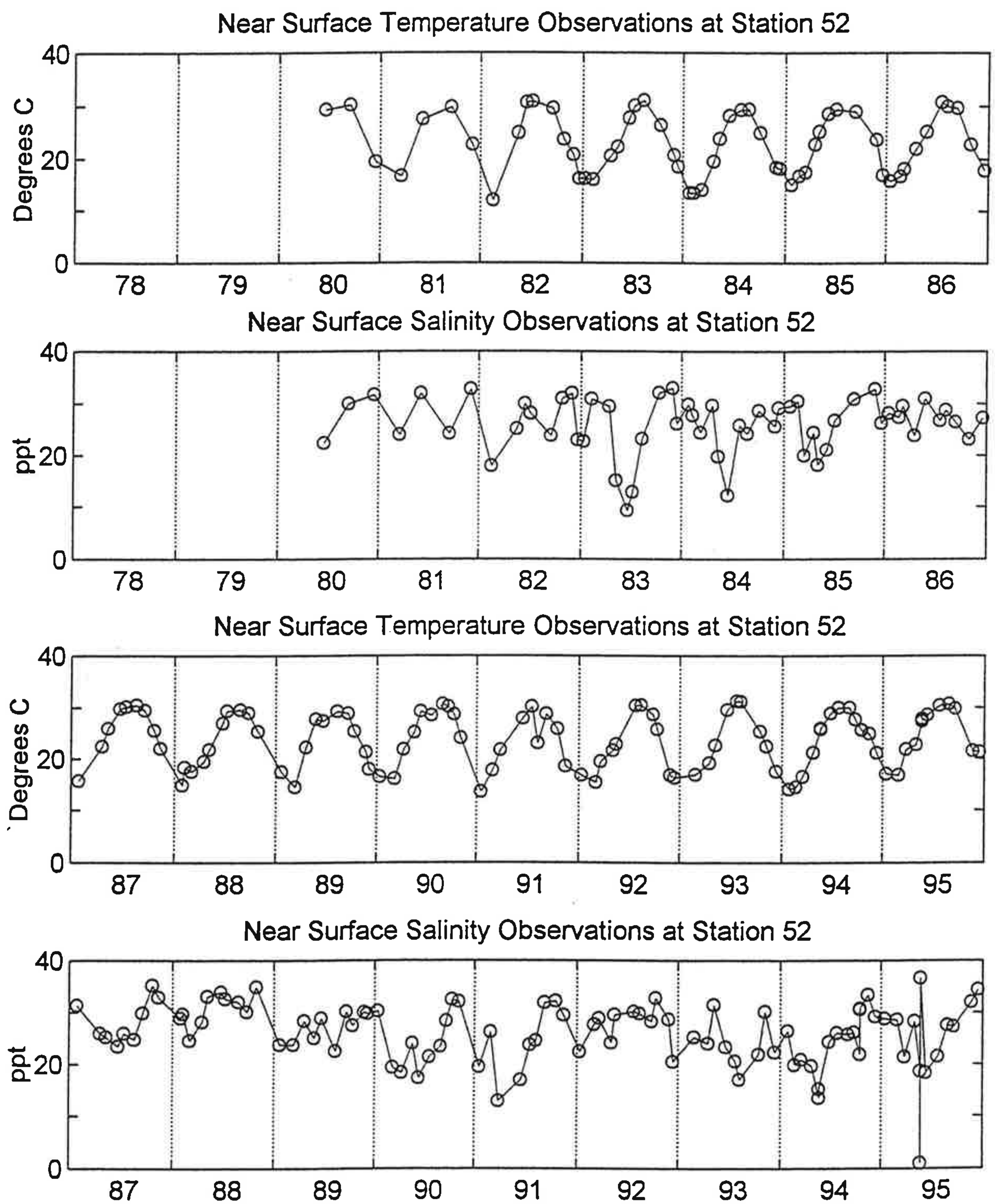

Figure B20. Station 52 monthly physical hydrography data: top temperatures and salinities.

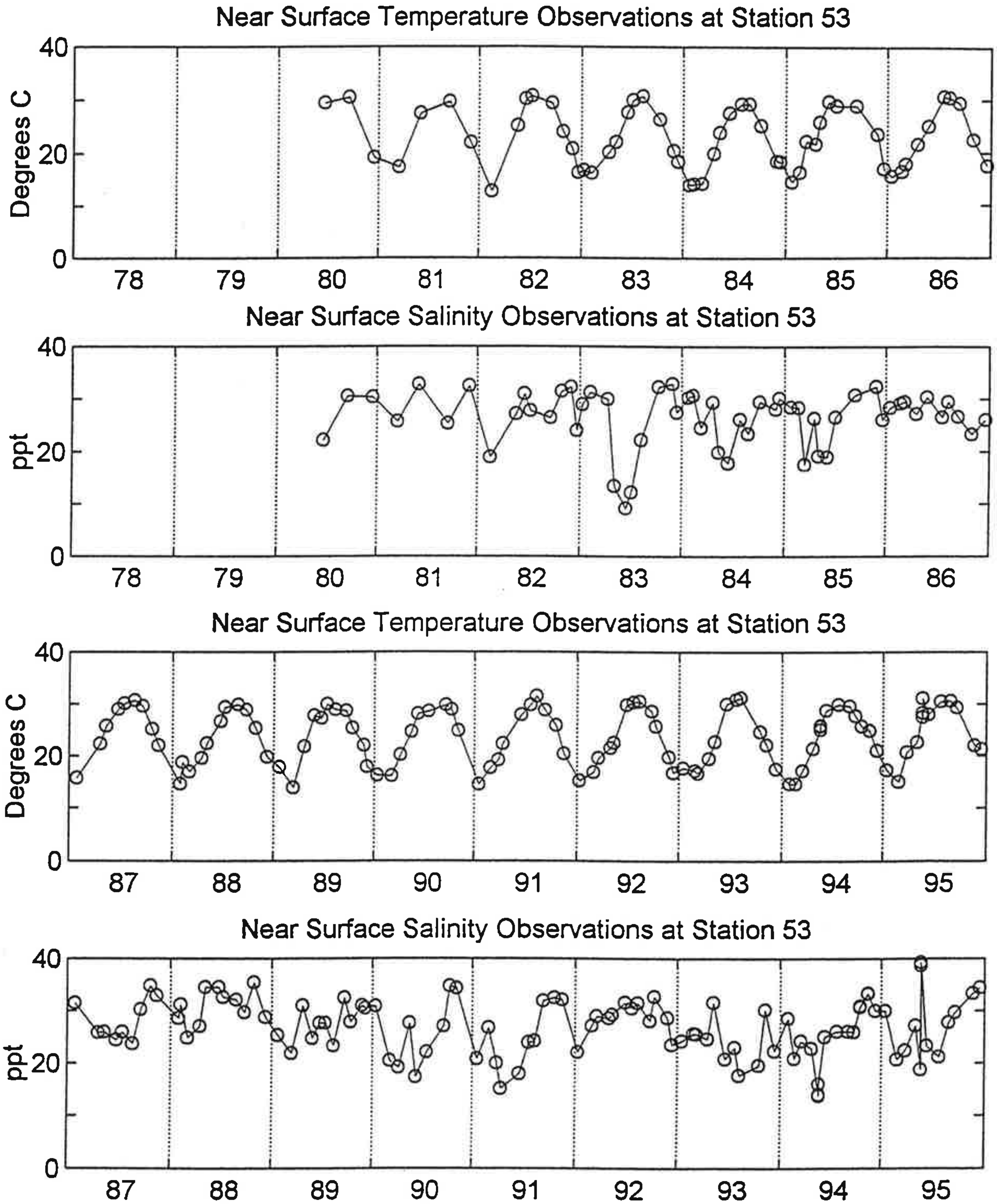

Figure B21. Station 53 monthly physical hydrography data: top temperatures and salinities.

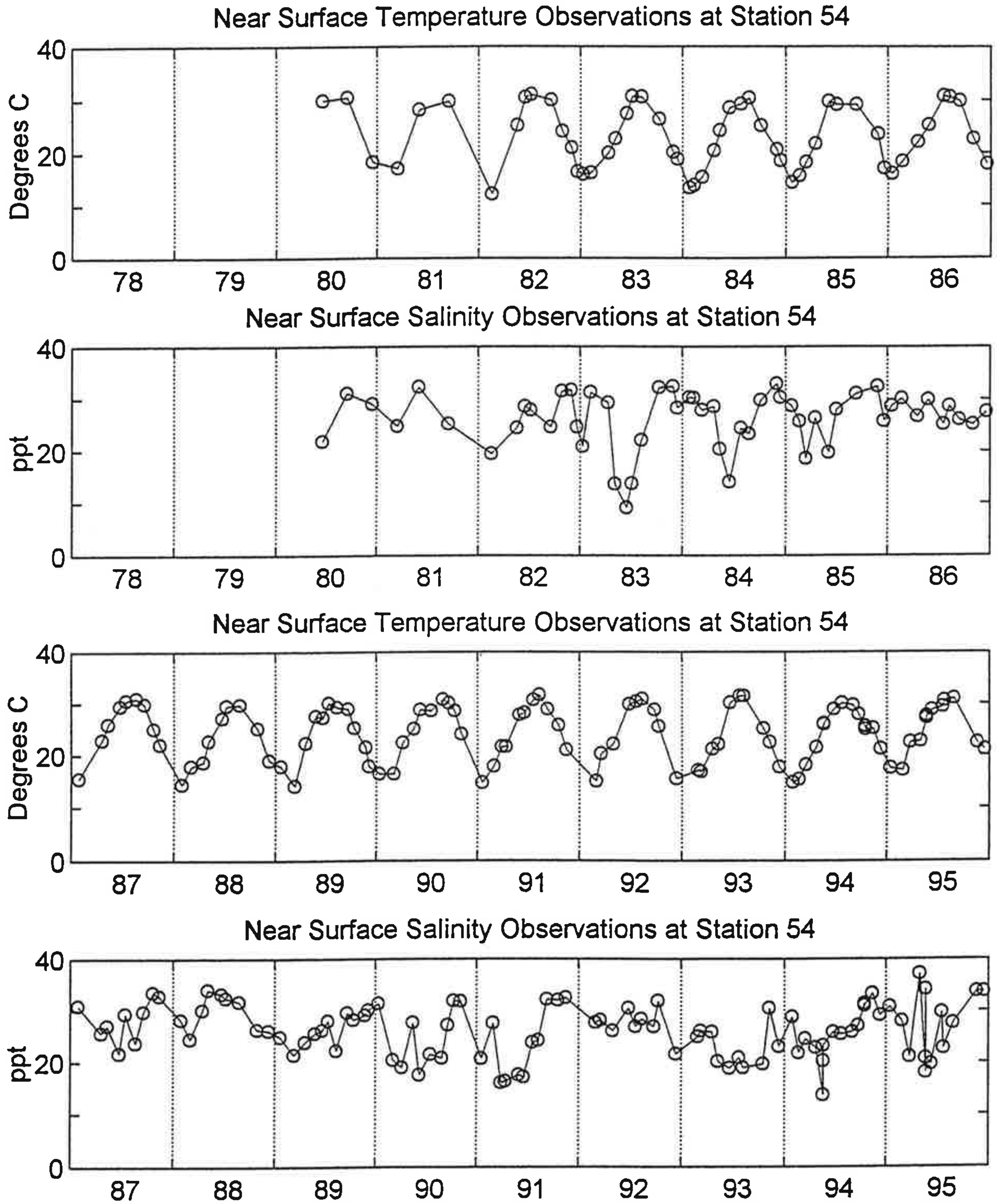

Figure B22. Station 54 monthly physical hydrography data: top temperatures and salinities.

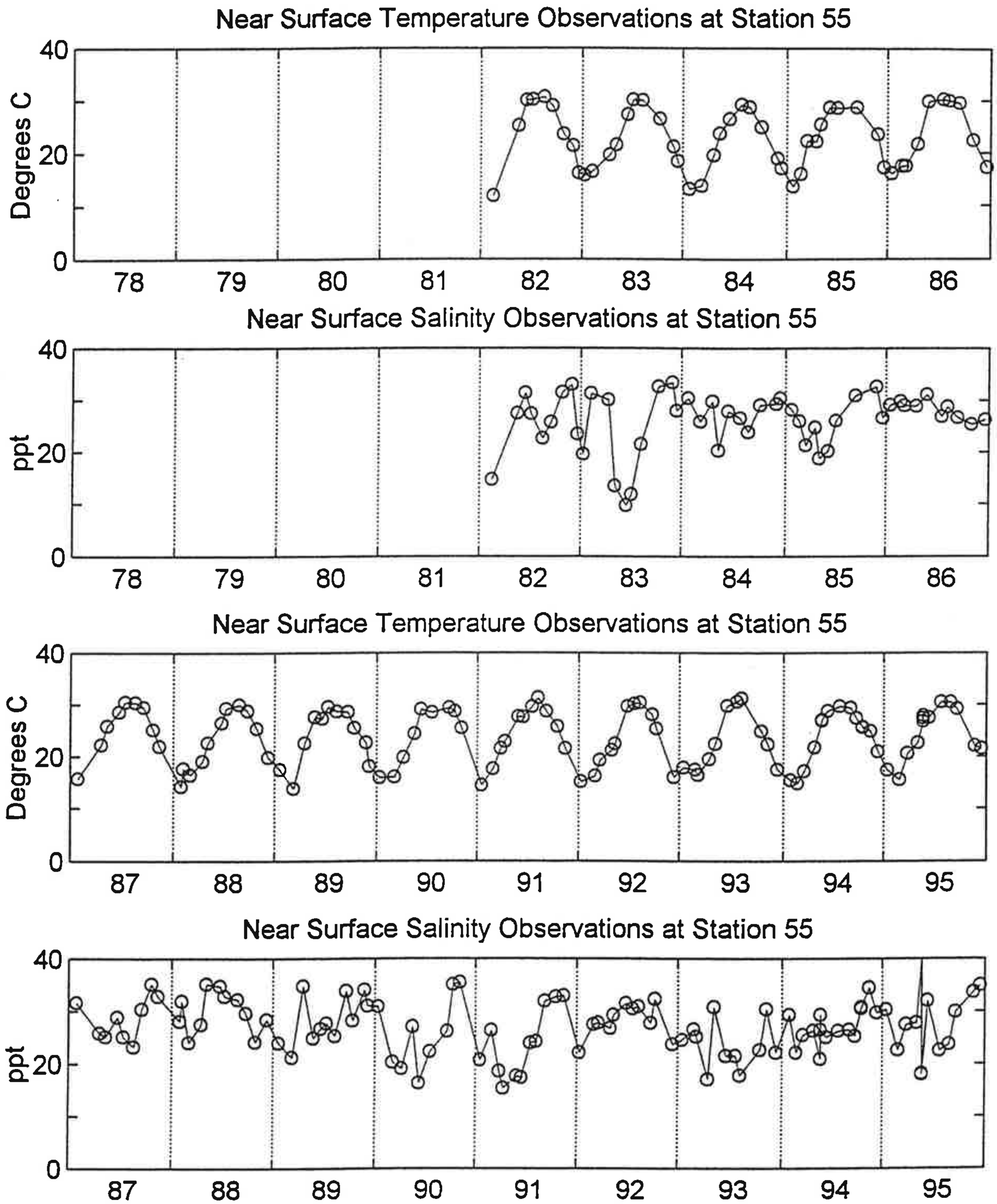

Figure B23. Station 55 monthly physical hydrography data: top temperatures and salinities.

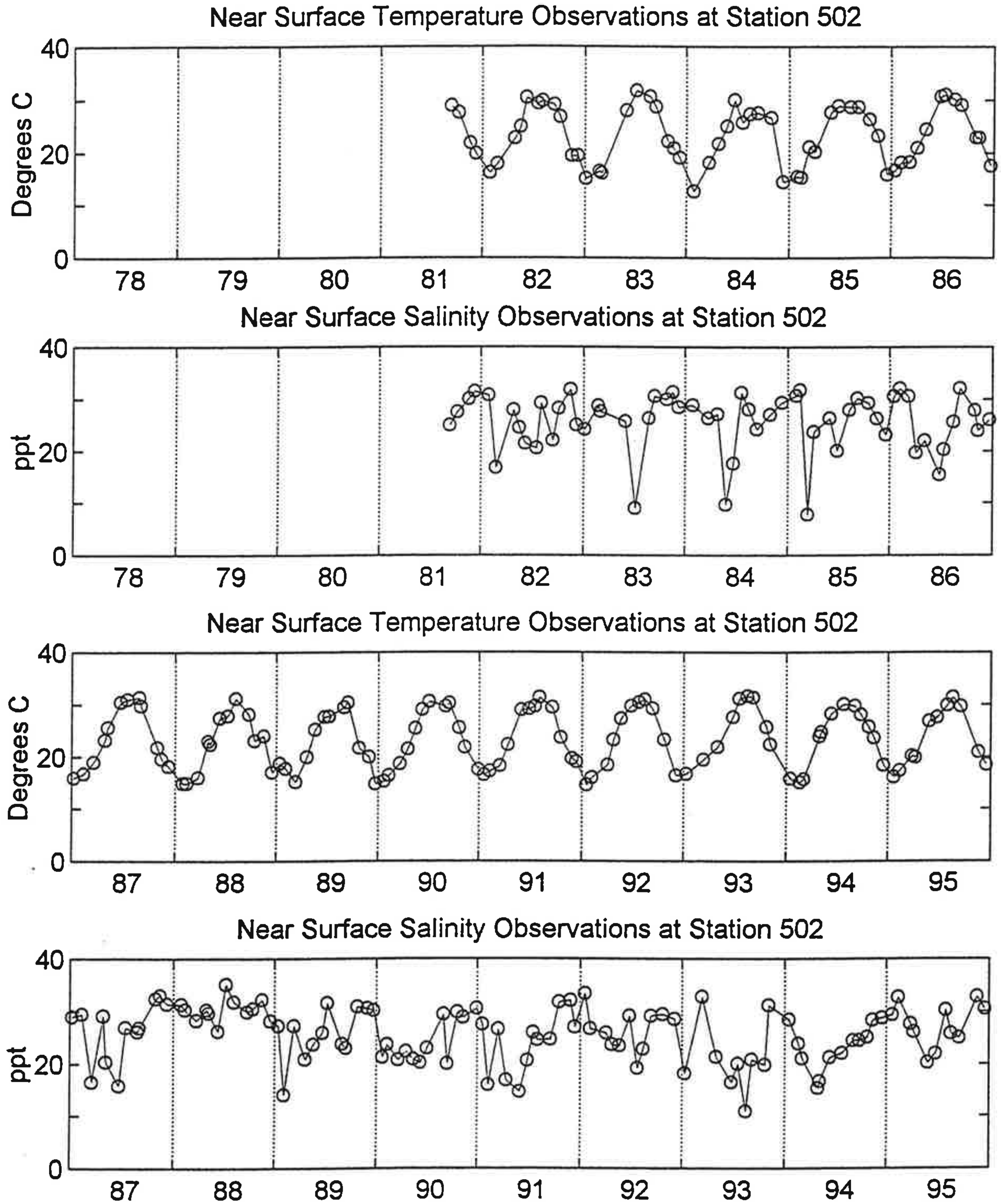

Figure B24. Station 502 monthly physical hydrography data: top temperatures and salinities.

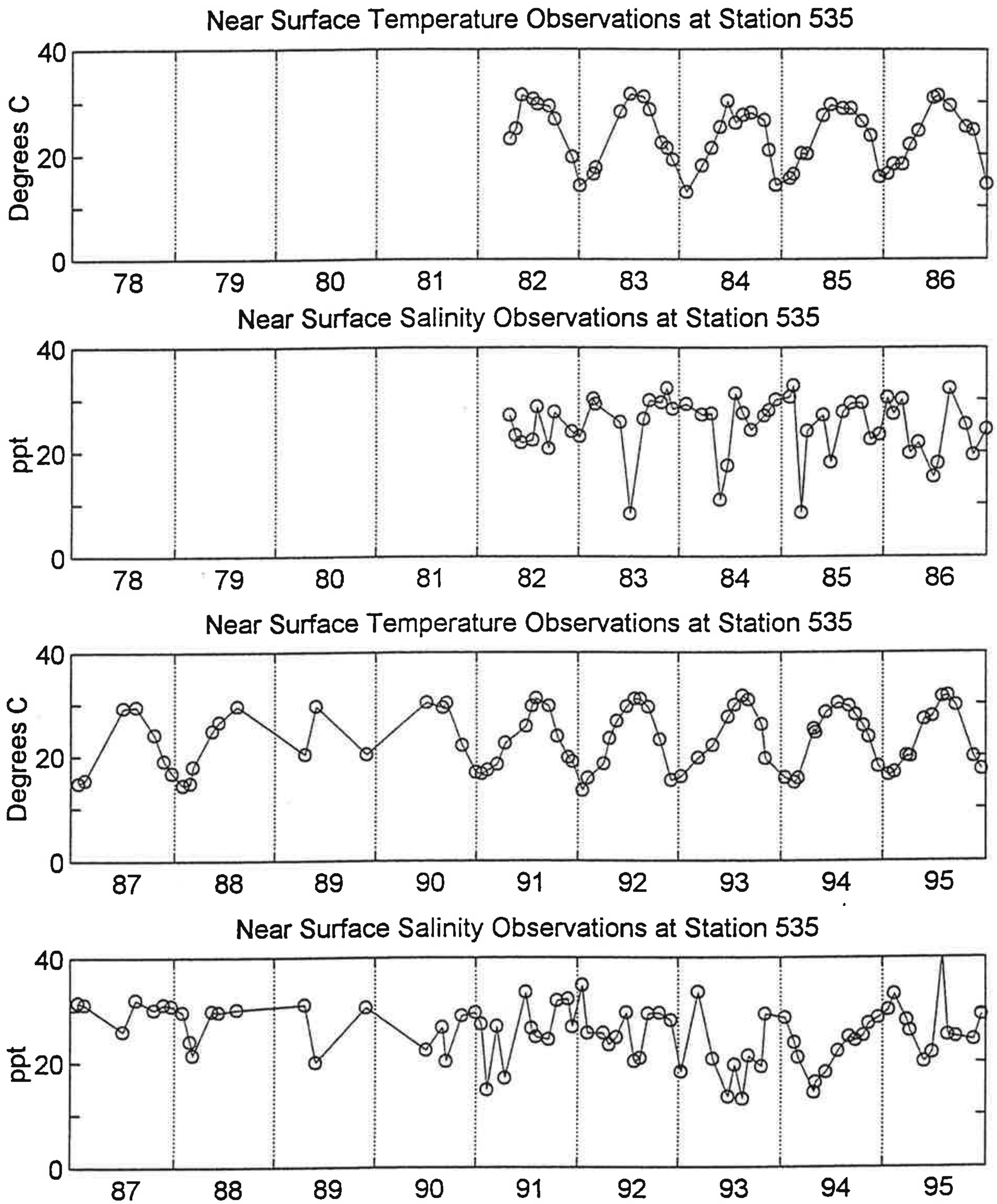

Figure B25. Station 535 monthly physical hydrography data: top temperatures and salinities.

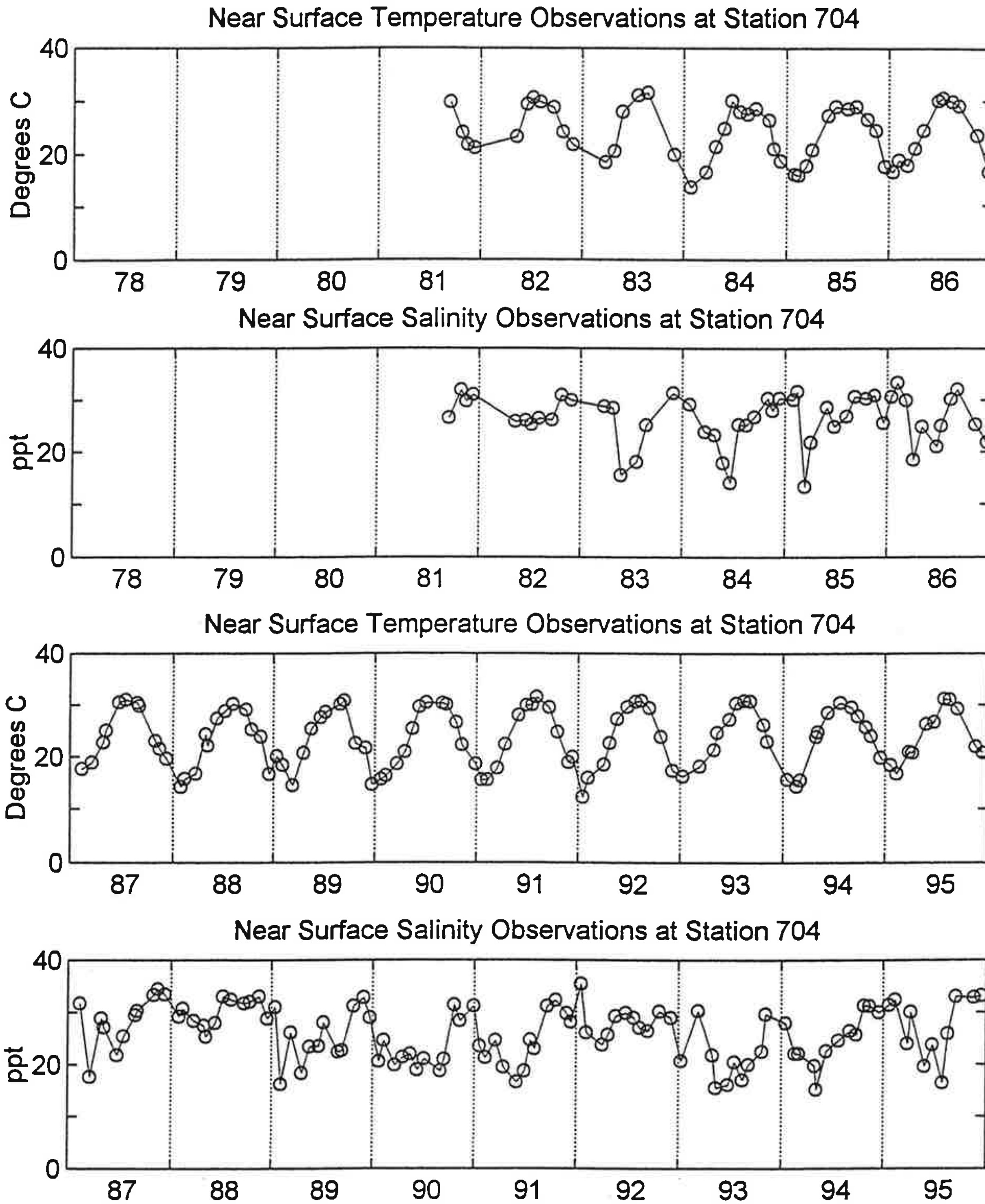

Figure B26. Station 704 monthly physical hydrography data: top temperatures and salinities.

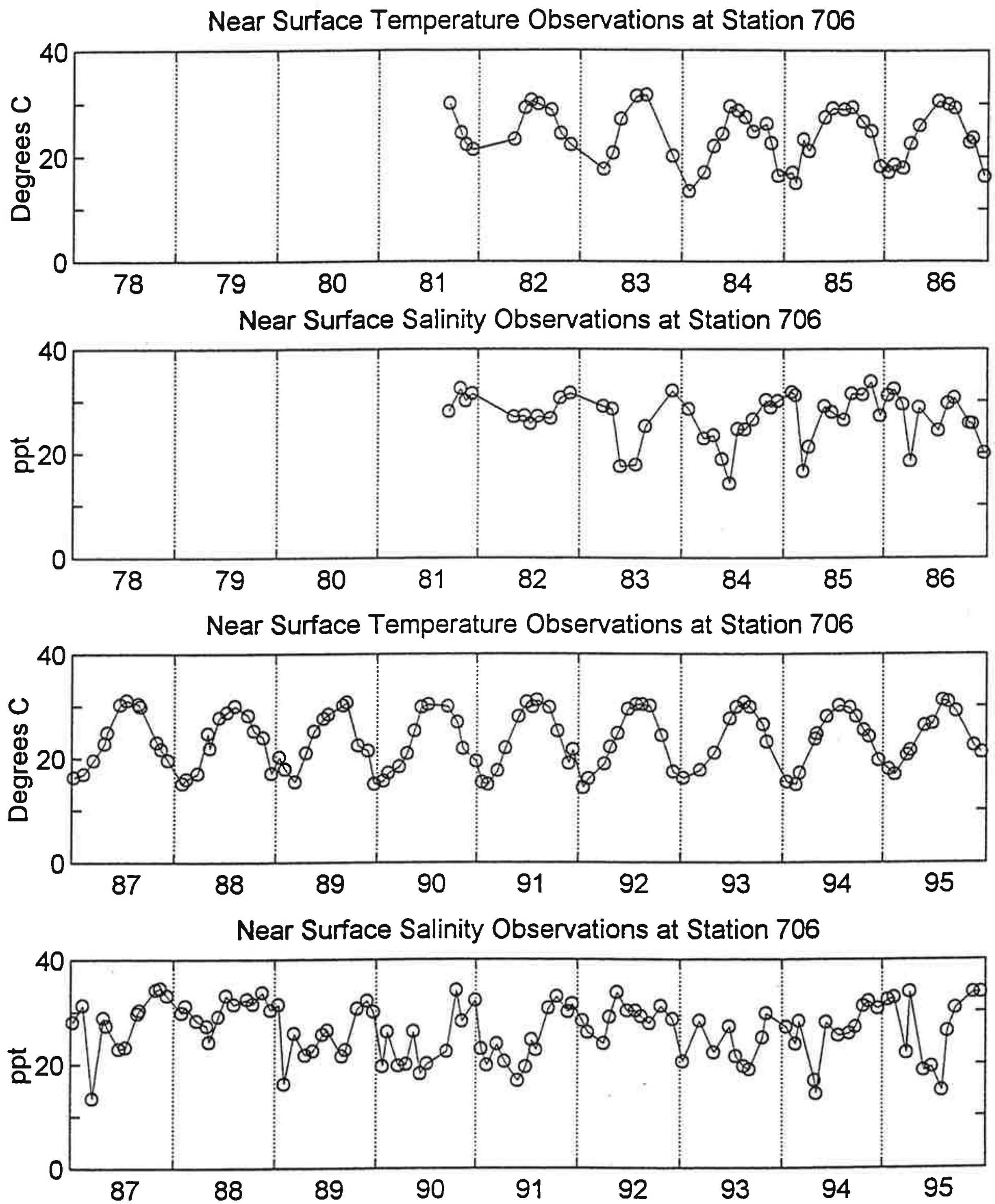

Figure B27. Station 706 monthly physical hydrography data: top temperatures and salinities.

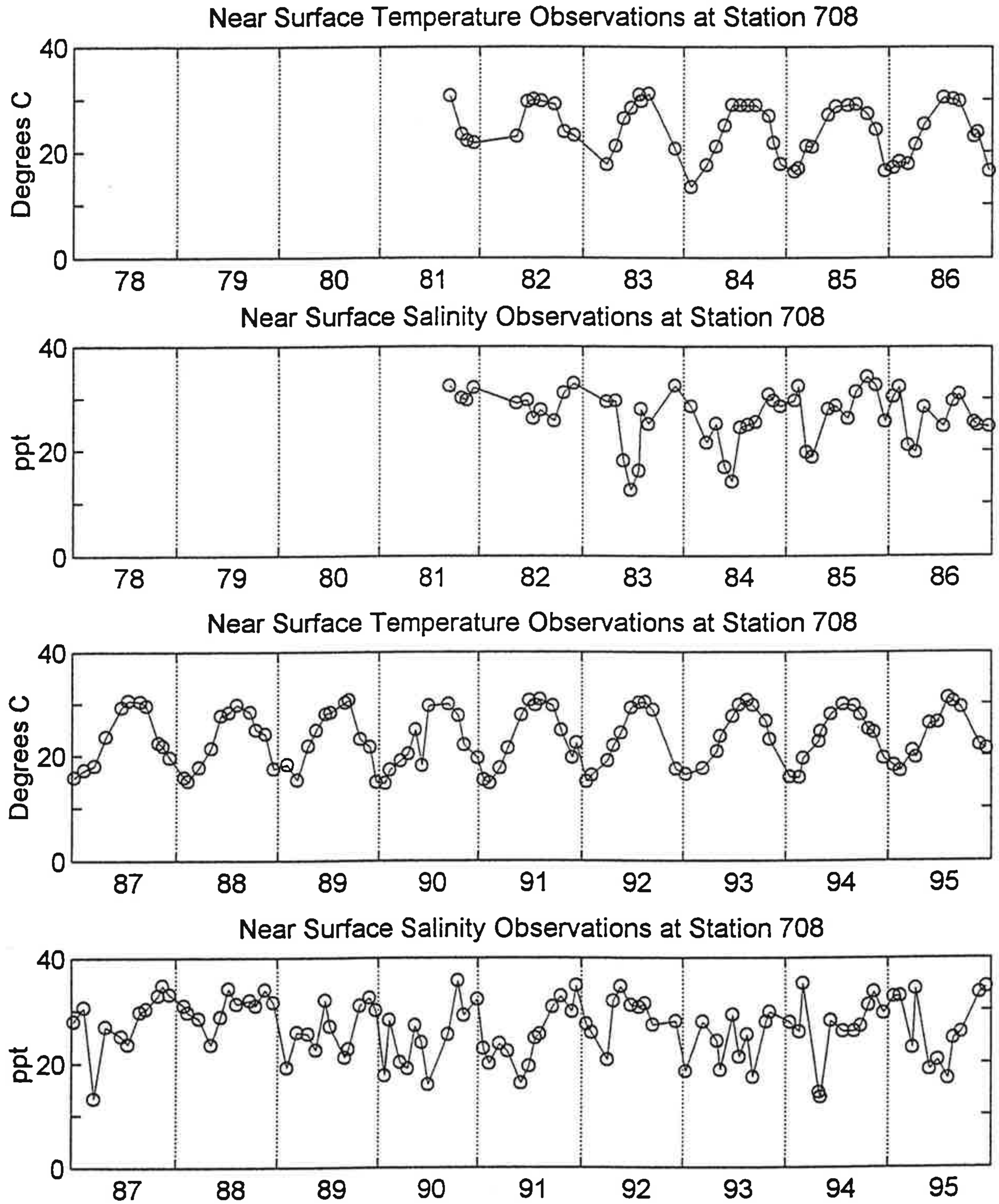

Figure B28. Station 708 monthly physical hydrography data: top temperatures and salinities.

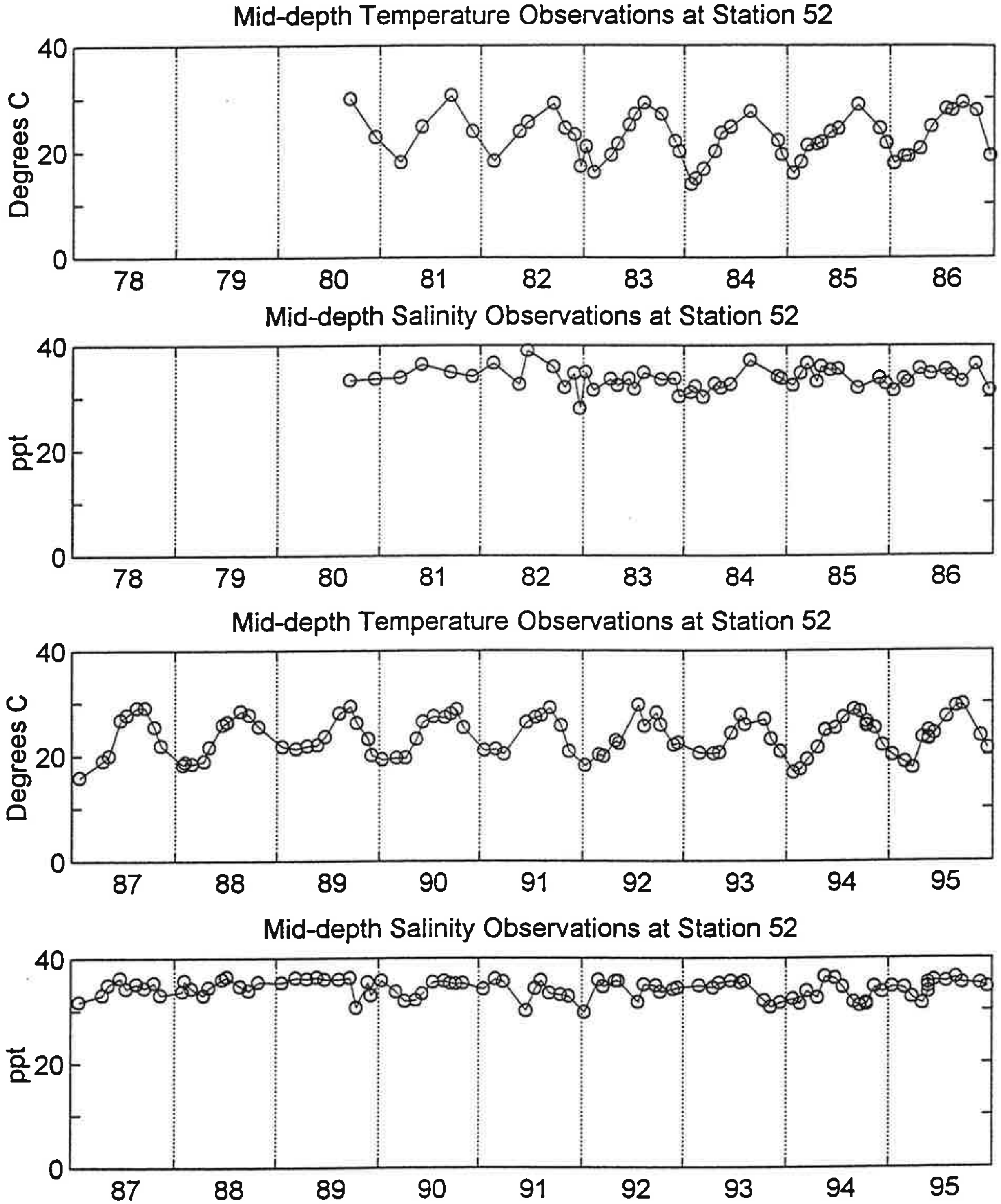

Figure B29. Station 52 monthly physical hydrography data: middle temperatures and salinities.

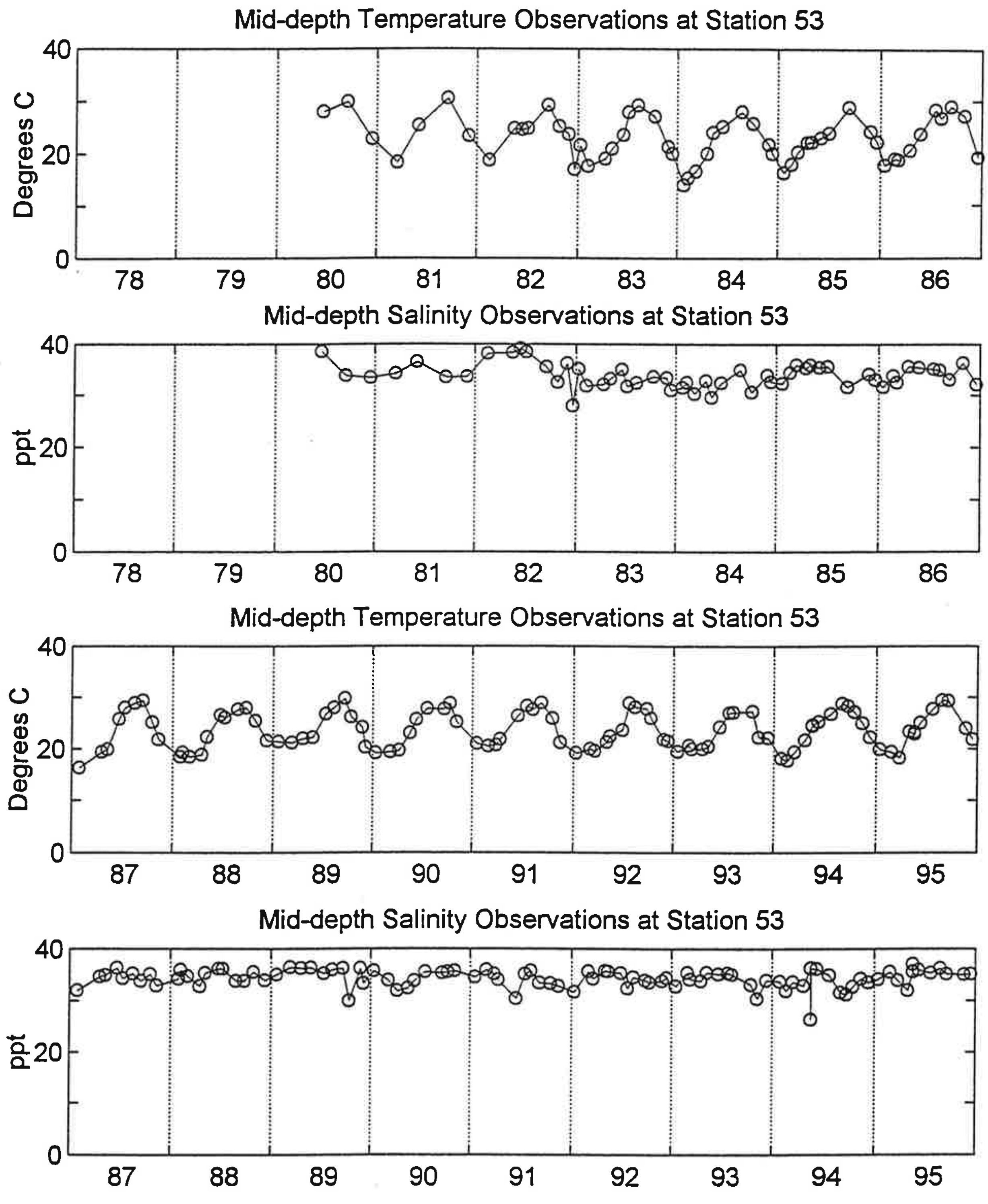

Figure B30. Station 53 monthly physical hydrography data: middle temperatures and salinities.

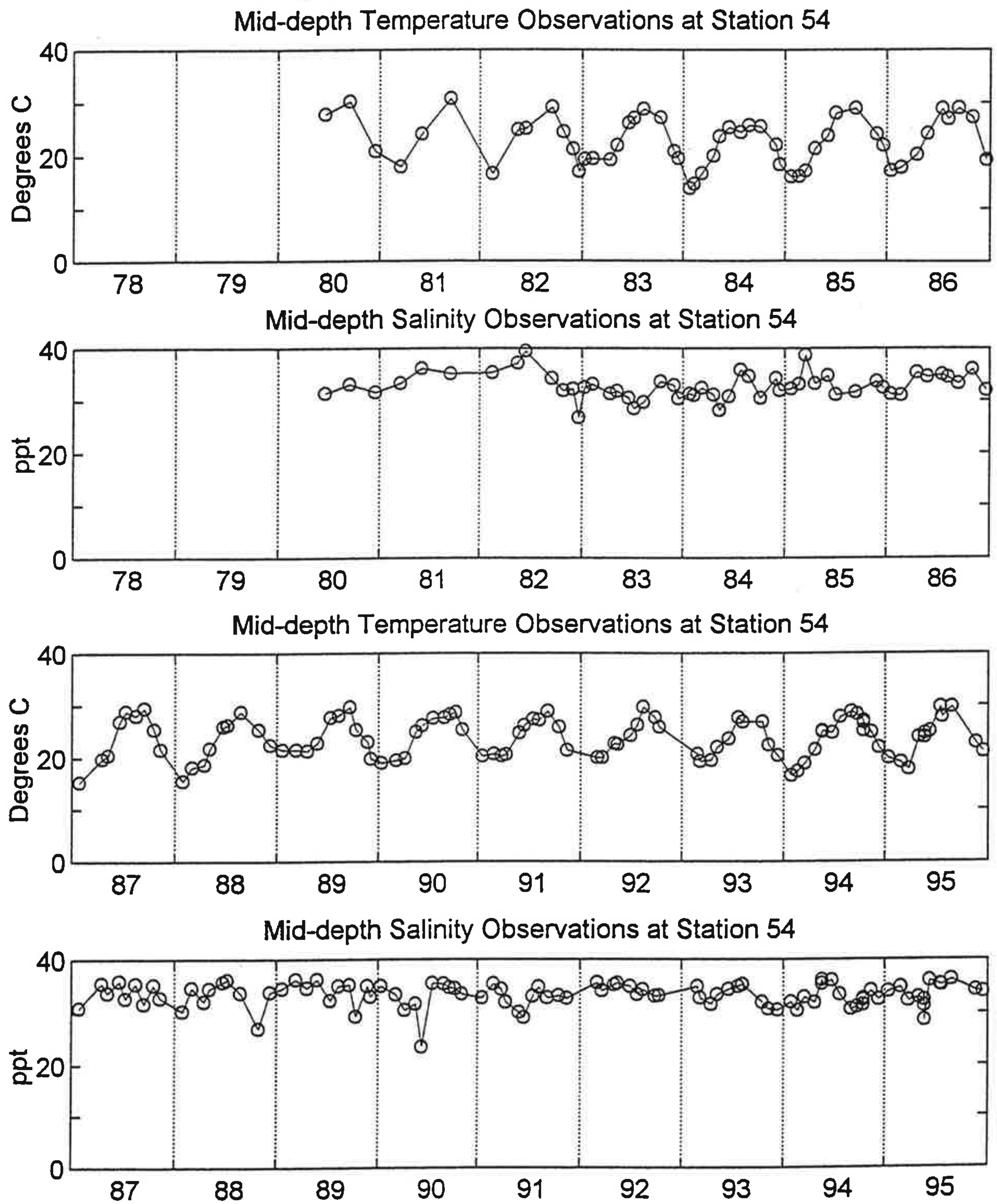

Figure B31. Station 54 monthly physical hydrography data: middle temperatures and salinities.

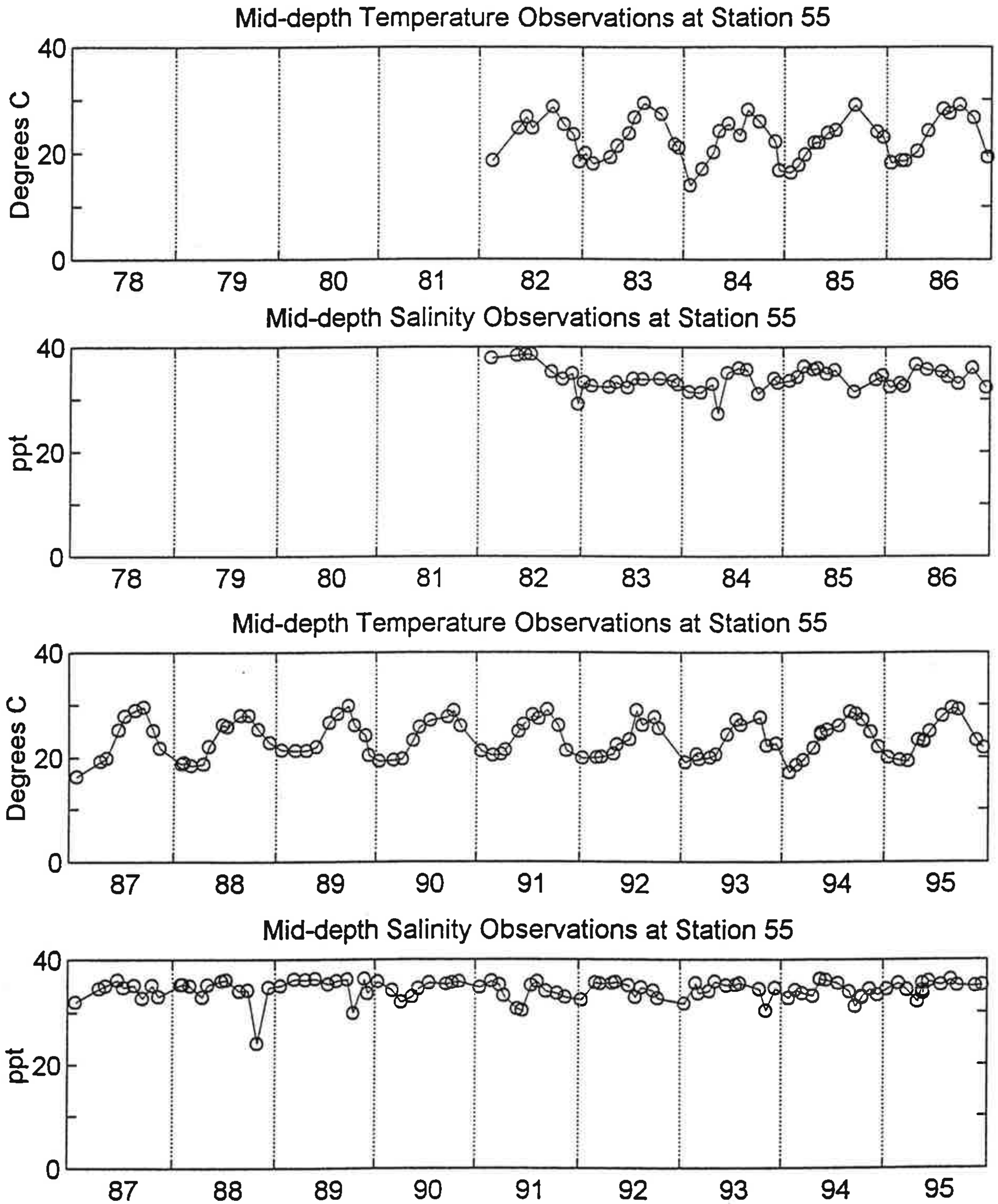

Figure B32. Station 55 monthly physical hydrography data: middle temperatures and salinities.

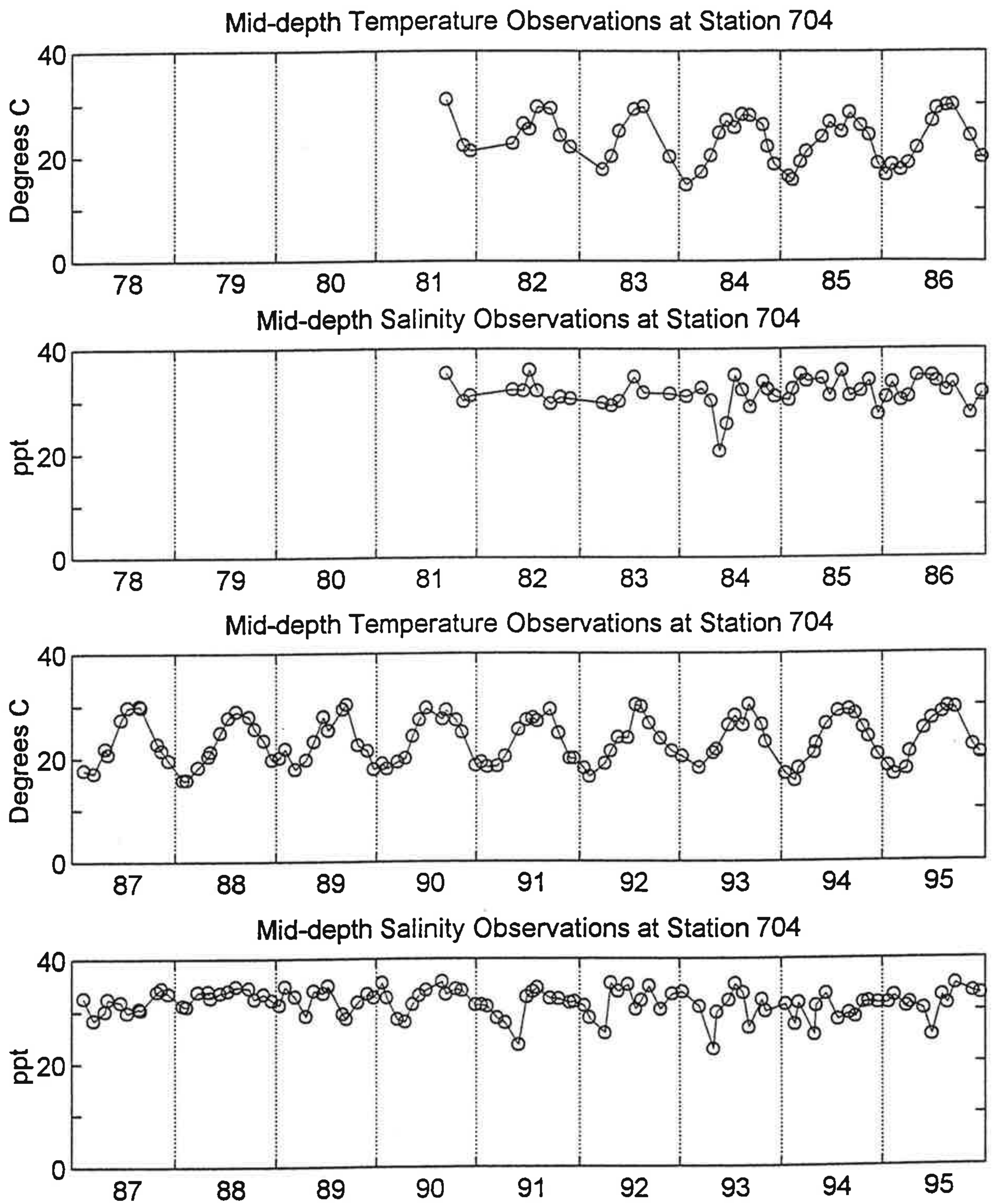

Figure B33. Station 704 monthly physical hydrography data: middle temperatures and salinities.

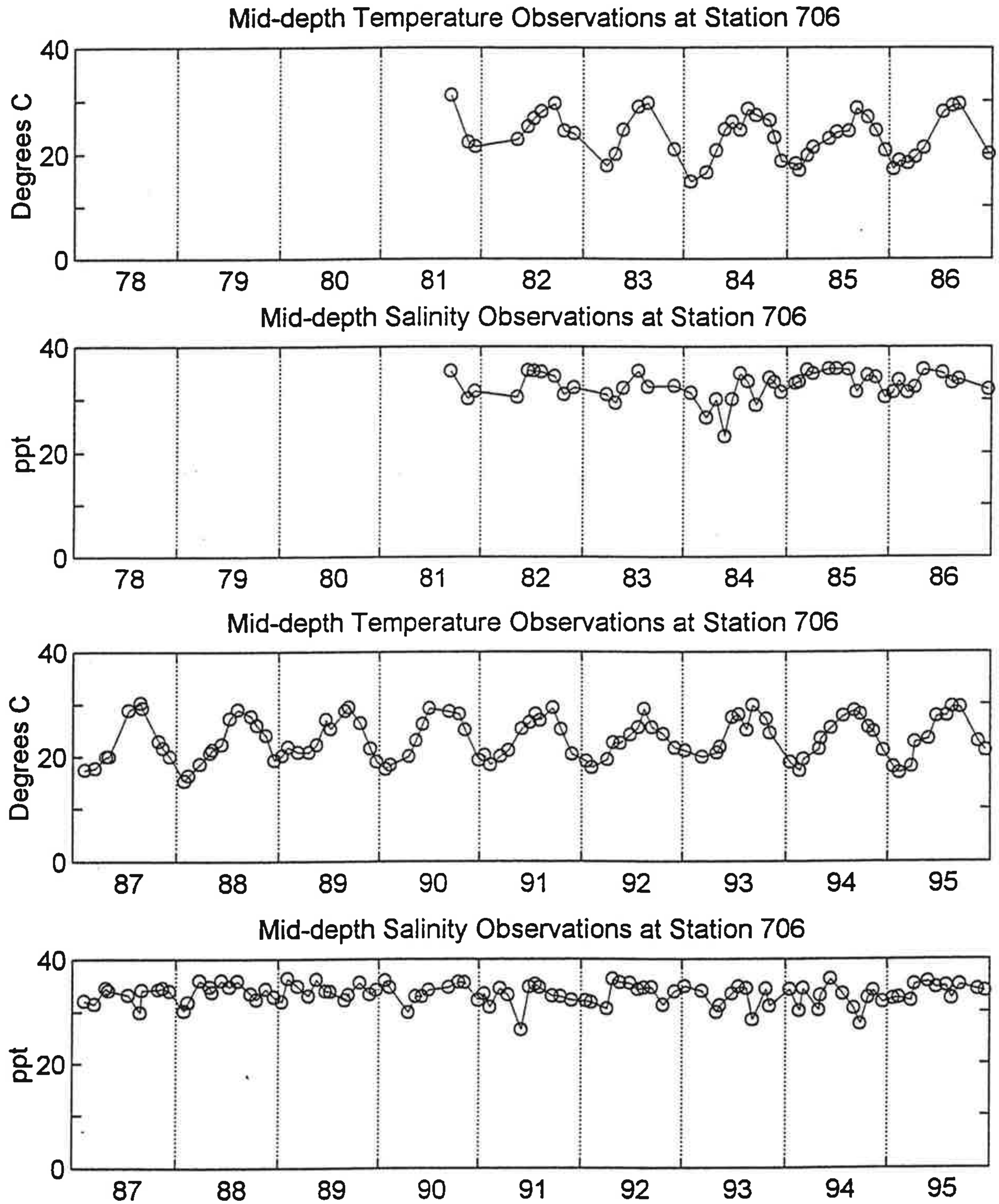

Figure B34. Station 706 monthly physical hydrography data: middle temperatures and salinities.

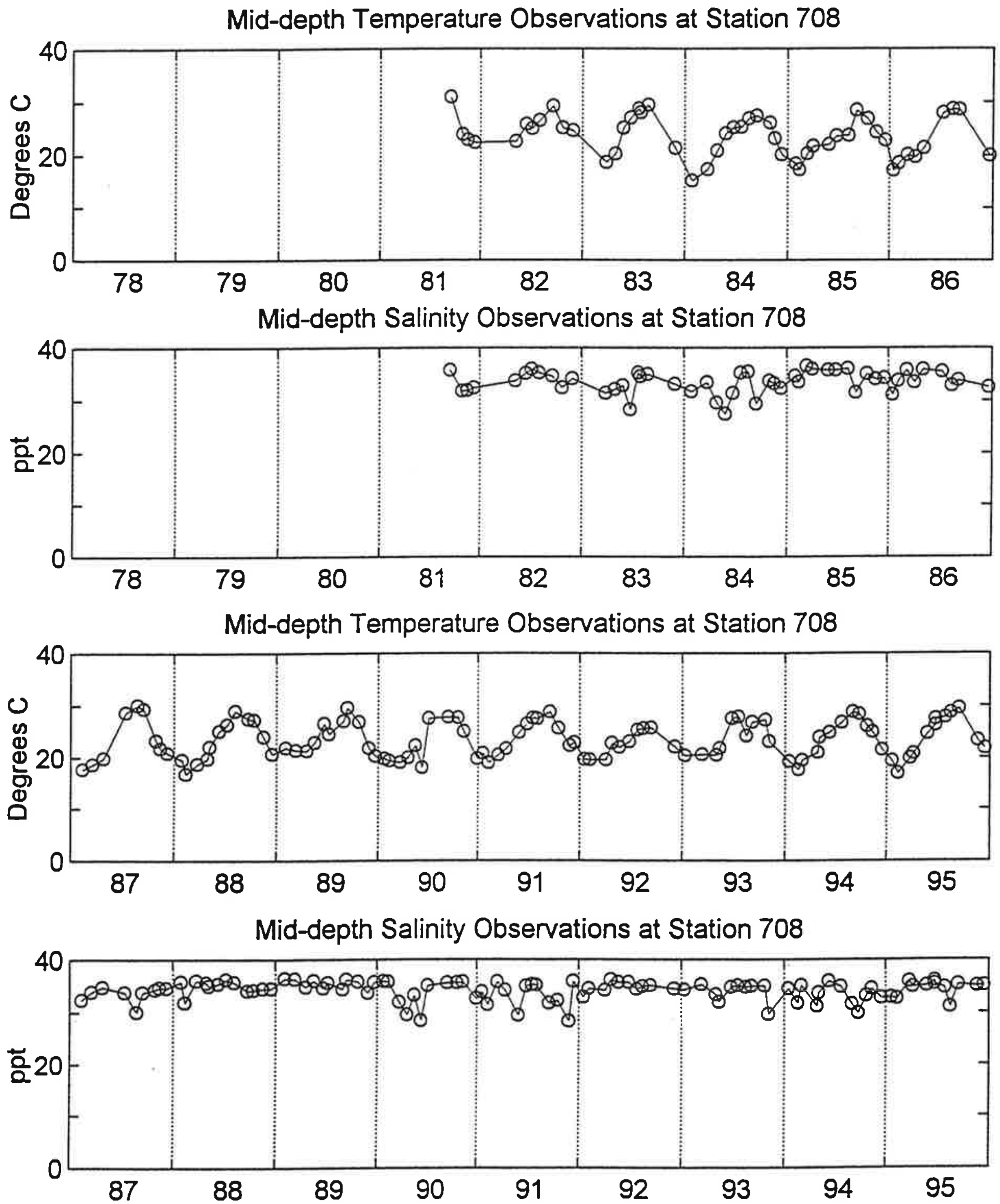

Figure B35. Station 708 monthly physical hydrography data: middle temperatures and salinities.

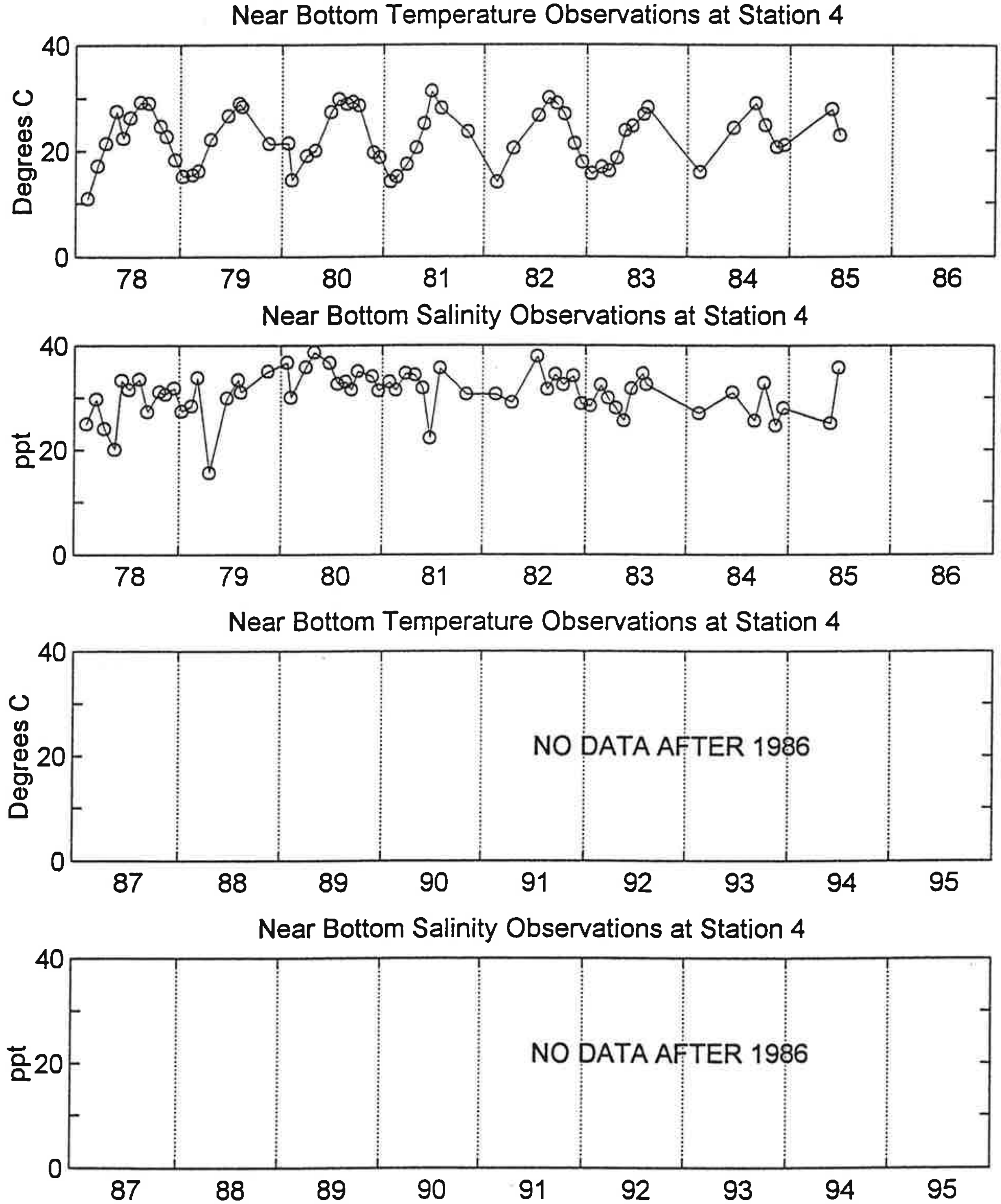

Figure B36. Station 4 monthly physical hydrography data: bottom temperatures and salinities.

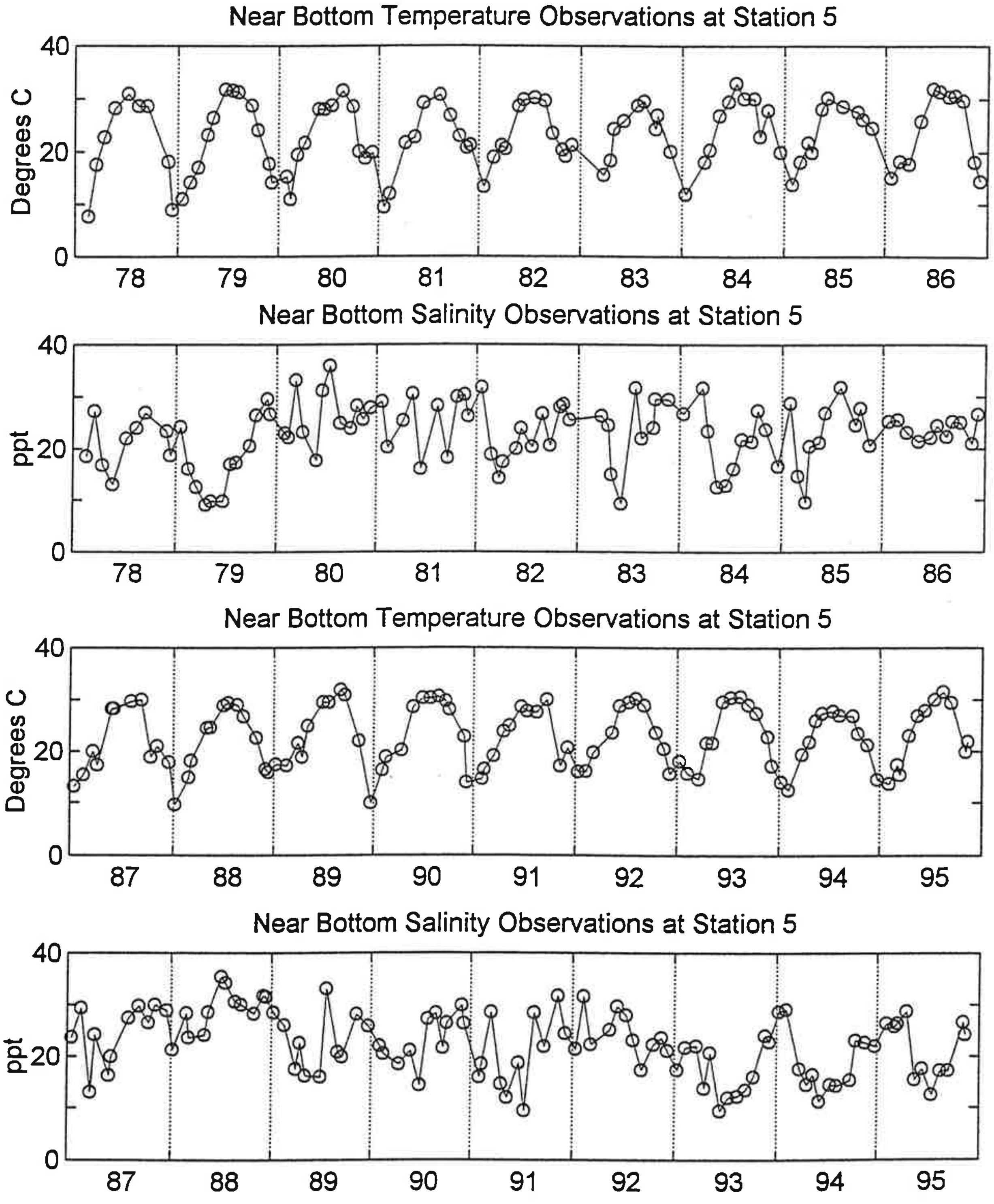

Figure B37. Station 5 monthly physical hydrography data: bottom temperatures and salinities.

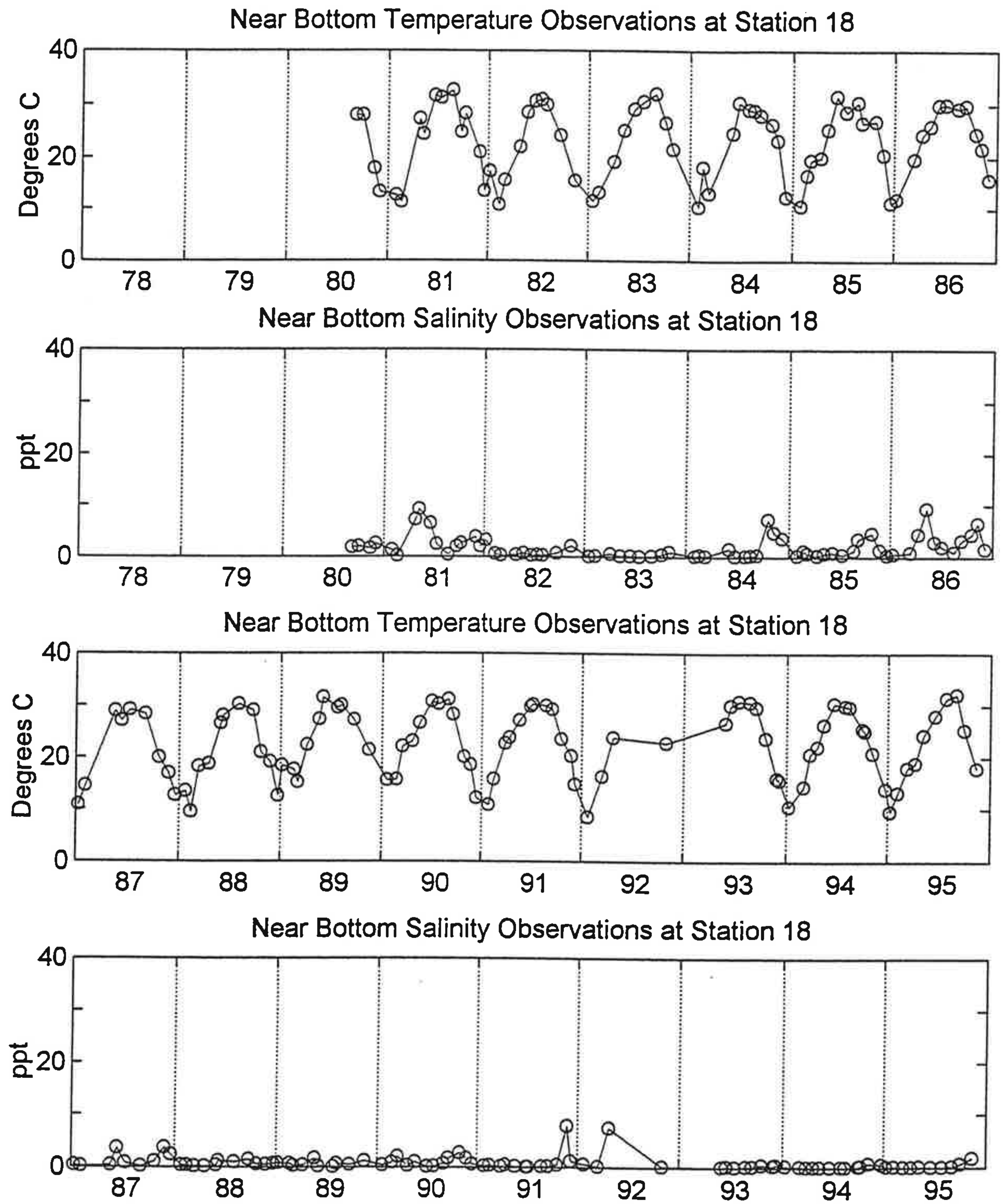

Figure B38. Station 18 monthly physical hydrography data: bottom temperatures and salinities.

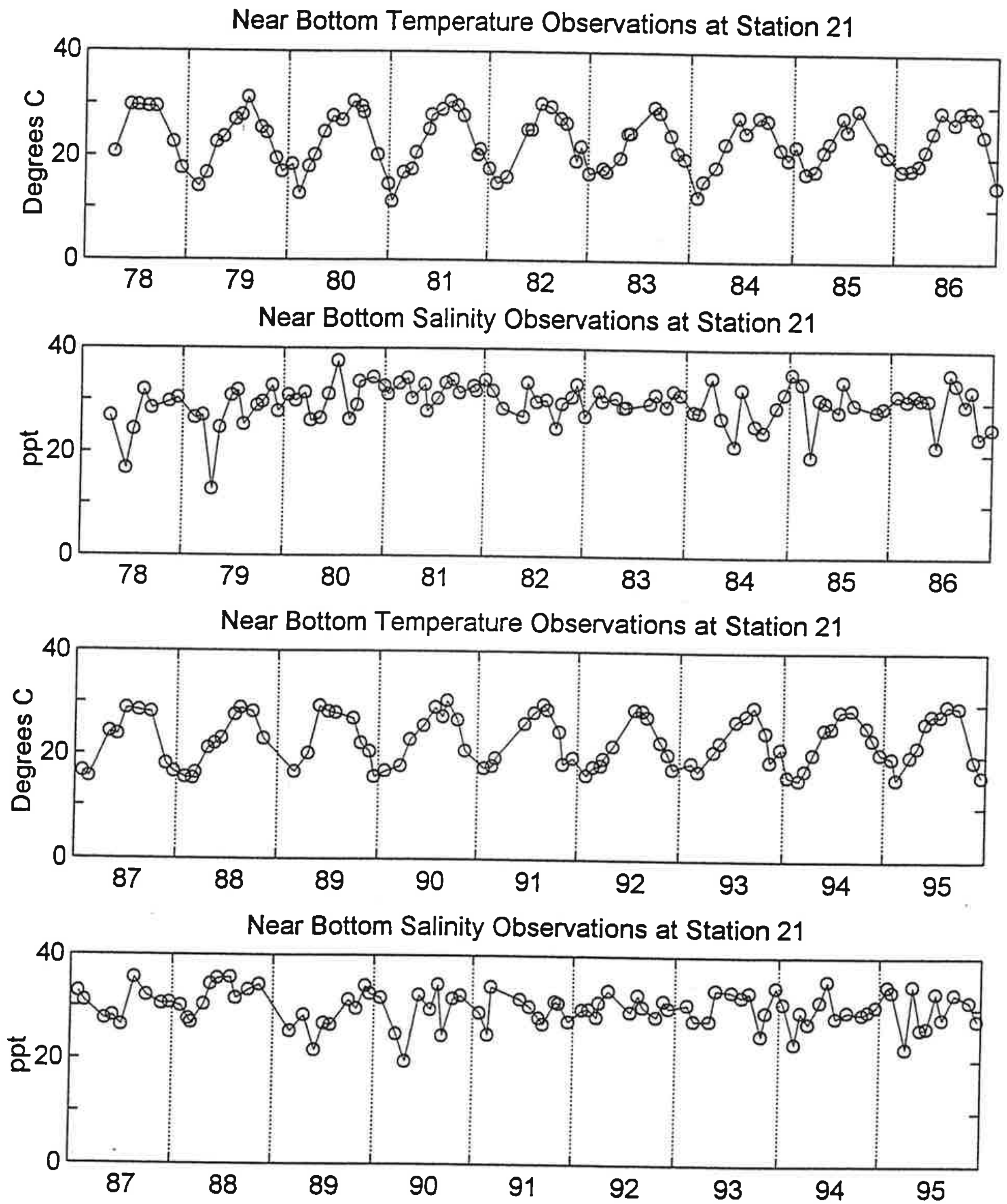

Figure B39. Station 21 monthly physical hydrography data: bottom temperatures and salinities.

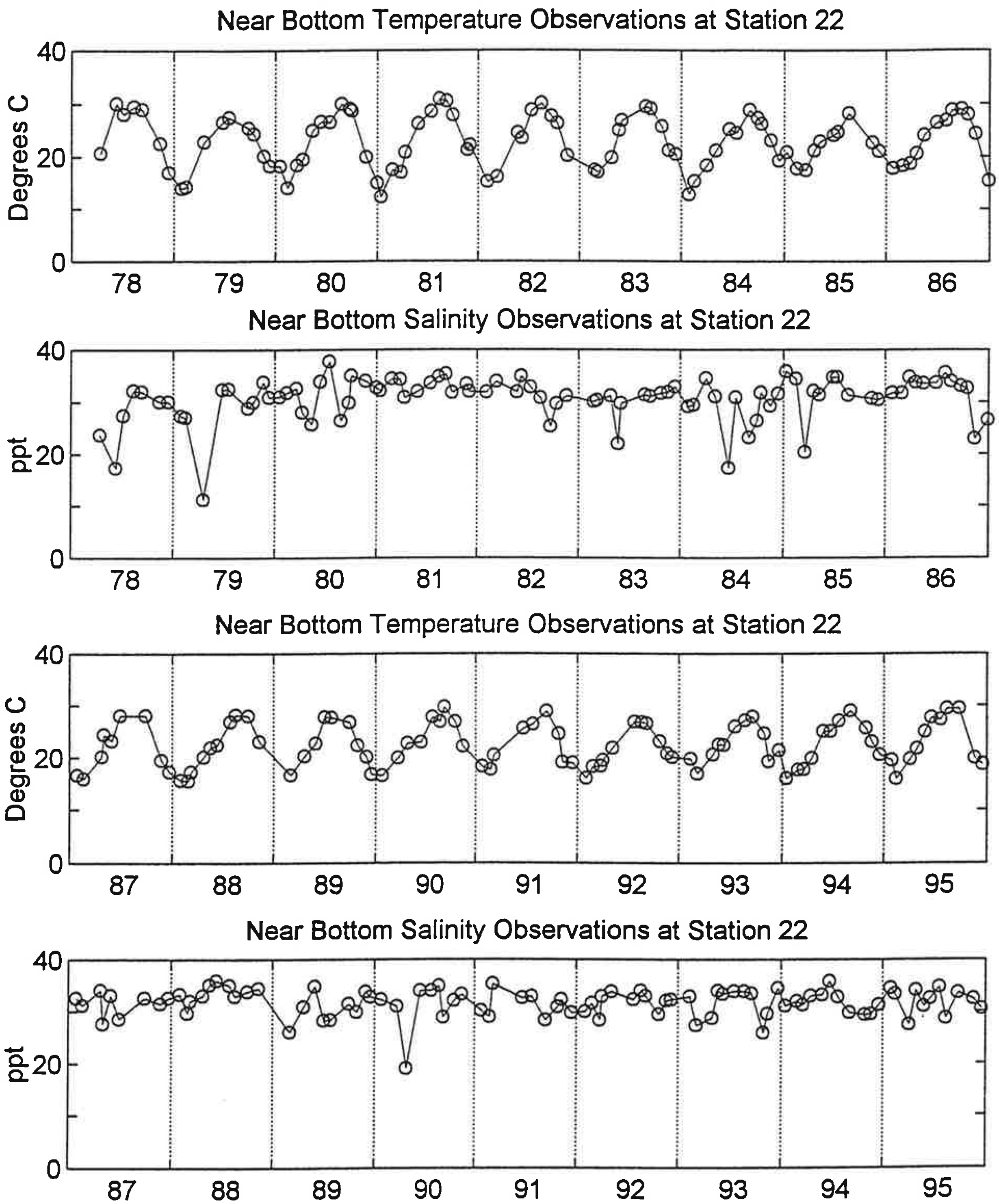

Figure B40. Station 22 monthly physical hydrography data: bottom temperatures and salinities.

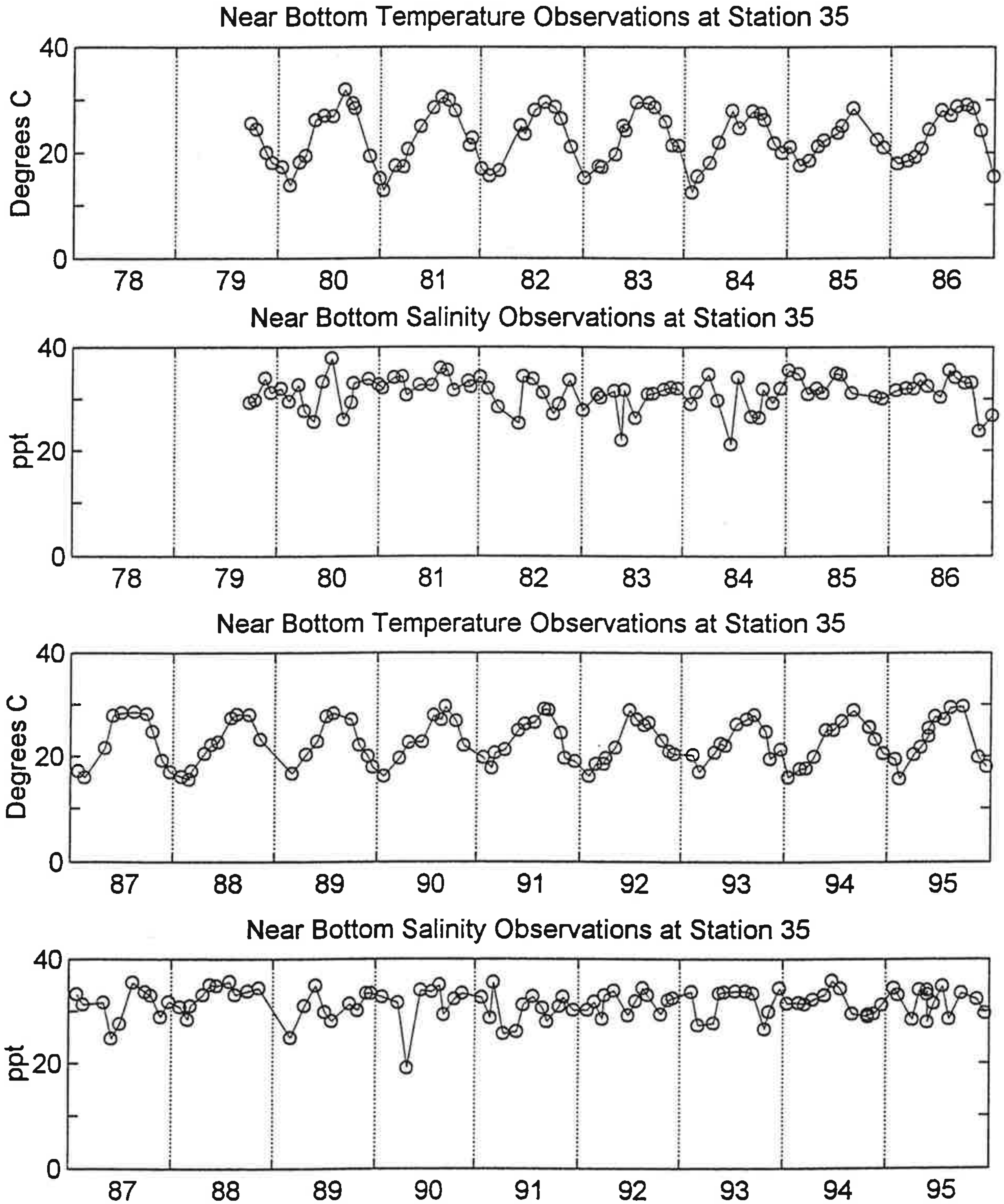

Figure B41. Station 35 monthly physical hydrography data: bottom temperatures and salinities.

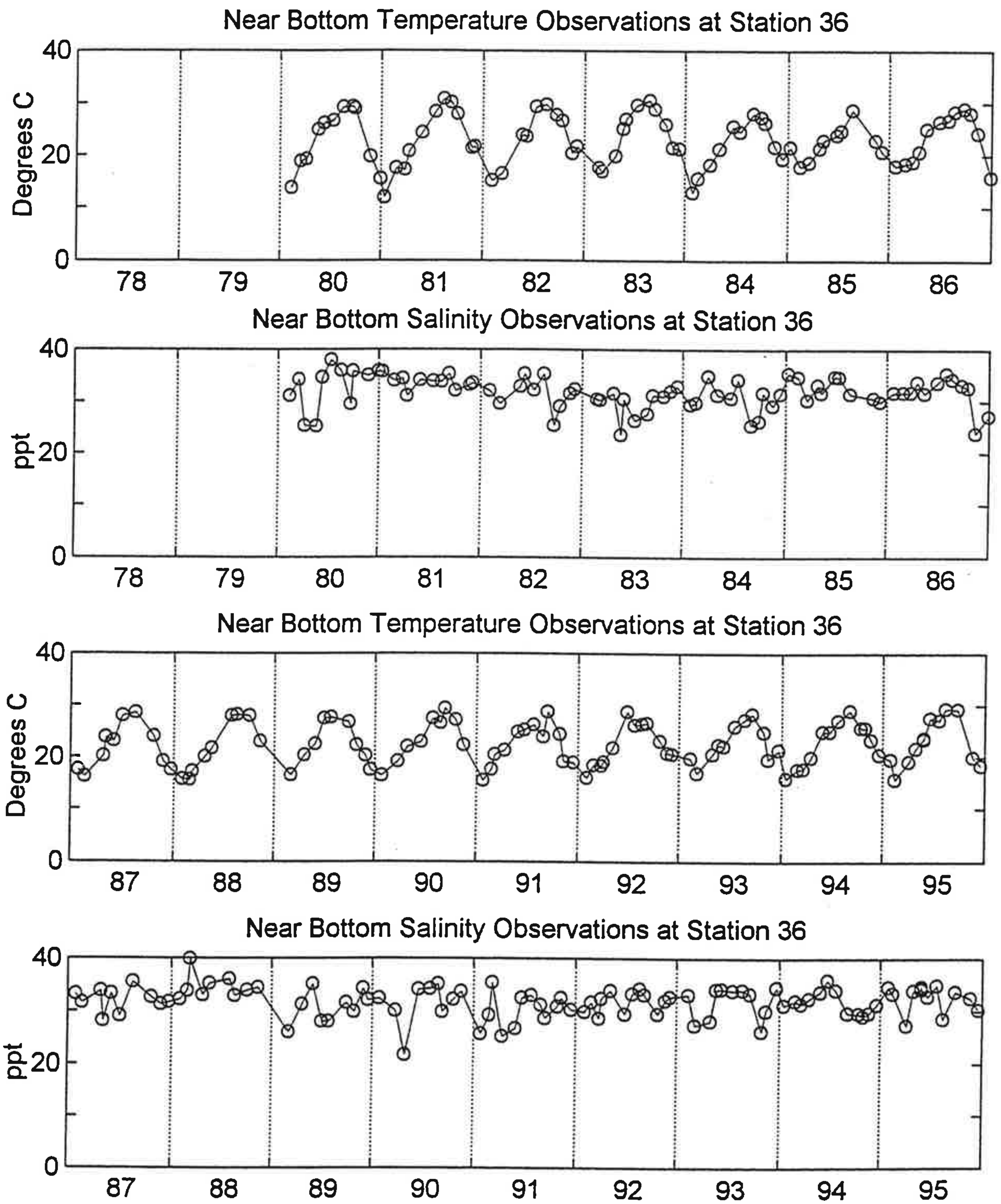

Figure B42. Station 36 monthly physical hydrography data: bottom temperatures and salinities.

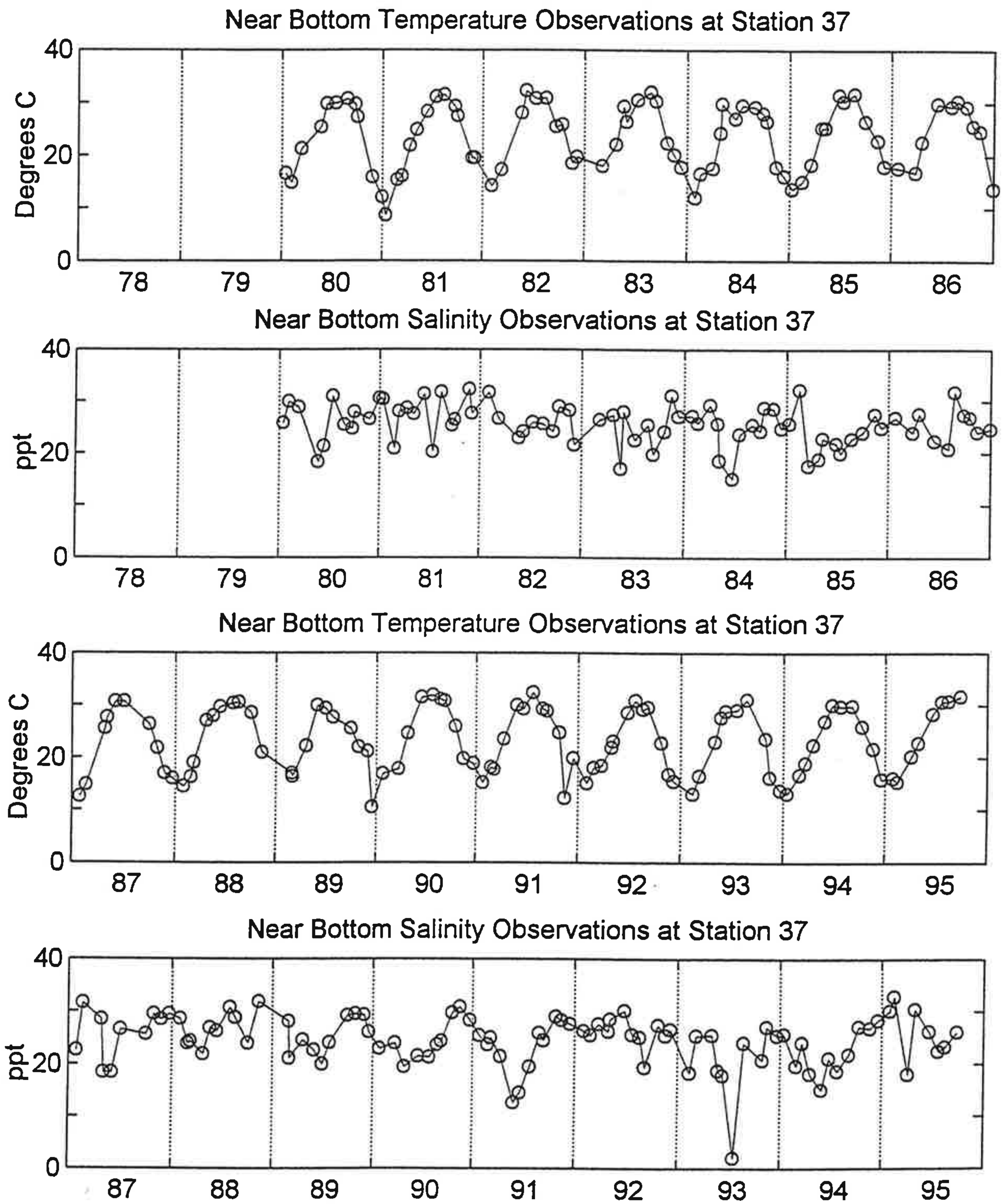

Figure B43. Station 37 monthly physical hydrography data: bottom temperatures and salinities.

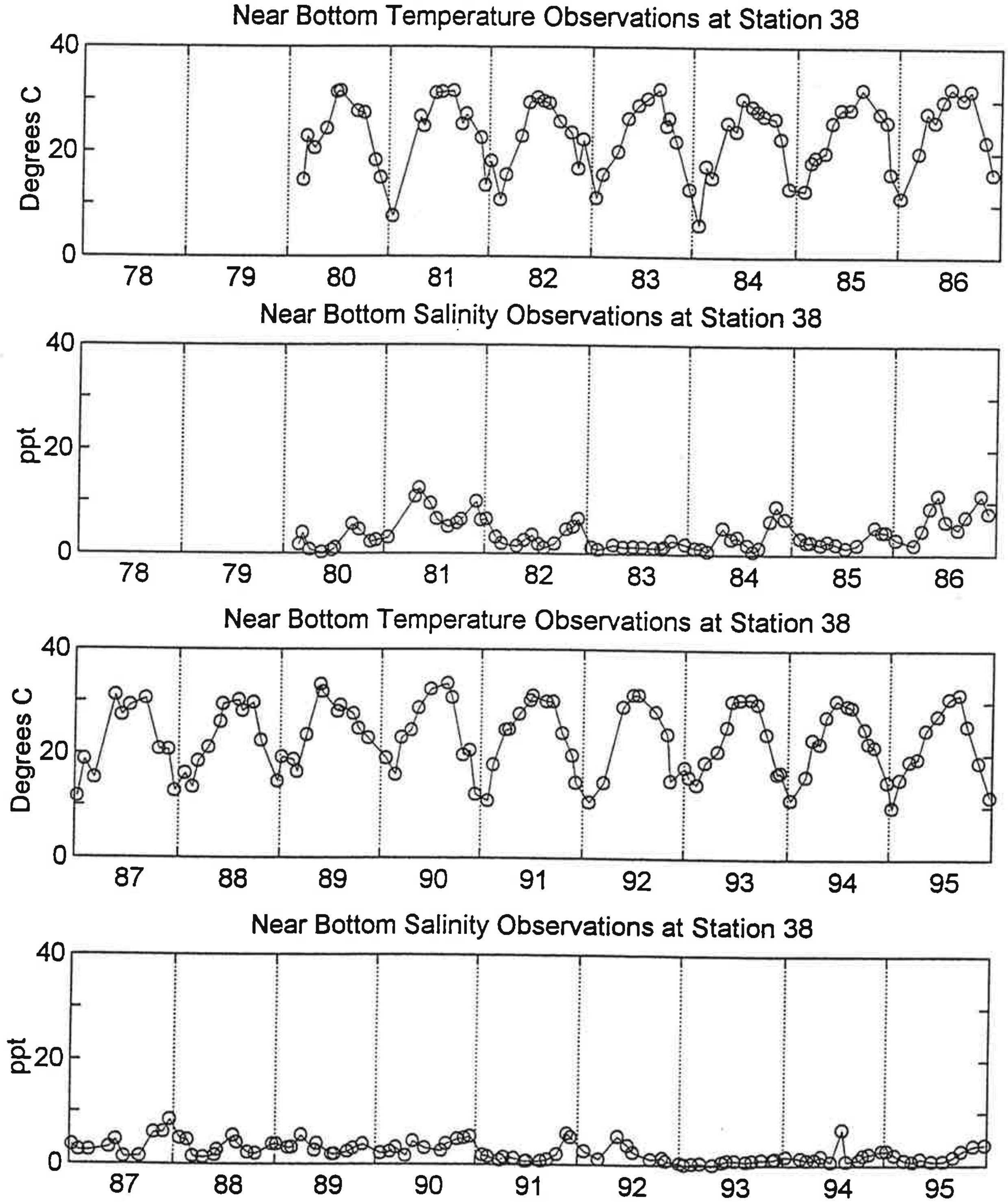

Figure B44. Station 38 monthly physical hydrography data: bottom temperatures and salinities.